1-25-1907

Ordinary Meeting, The Panama Canal, The Lock Canal type and the Straits of Panama Type

Kentucky Library Research Collections
Western Kentucky University, spcol@wku.edu

No. 2827. VOL. LV. JAN. 25, 1907.

PUBLISHED EVERY FRIDAY.

JOURNAL of the SOCIETY OF ARTS

CONTENTS

For detailed Table of Contents see Page ii.

price to non-members 6d.

LONDON PUBLISHED FOR THE SOCIETY BY GEORGE BELL & SONS, YORK HOUSE, PORTUGAL ST. W.C.

Registered as a Newspaper

stirs the surface of a virgin prairie, scattering in the seed meanwhile, and then leaves it to take its chance until harvest. Compare the highly technical routine of the hop grower who spends £50 per acre before he harvests his crop, his repeated cultivations, his manurings, his sprayings for various ends; it is with this kind of crop that science can find its most profitable employment.

Looking at the average yields of the various countries of the world we find that Great Britain is the most intensively farmed country; it obtains the biggest crops per acre, it has to spend the most to obtain them. Furthermore, the bigger the crop the greater are the risks of disease and blight, and the greater are the difficulties in securing high quality. Here then in Great Britain exists the greatest need for knowledge and investigation; nor can we always beg knowledge from wiser countries, for many of our problems are special and brought about by the very conditions of high farming which prevail here. England was the first country to start an experimental station, yet Rothamsted still remains the only institution solely devoted to agricultural research in the British Isles, if we except the farm of the Royal Agricultural Society at Woburn. The income of the Rothamsted Station, derived from private benefaction, is about £2,600 a year; in the United States each of the 53 States possesses a station receiving £3,000 a year from the Federal Government, in addition to what the State itself may contribute, while there is also the great Central Department of Agriculture, of which I have already spoken. Yet Rothamsted cannot obtain a grant from the Board of Agriculture to extend its operations; the country is too poor, agriculture too unimportant an industry.

I have wandered a little perhaps from the text of these lectures, but I have done so with a purpose; the use of artificial fertilisers is bound up with research, and Rothamsted has done so much for their investigation in the past that I may be pardoned in pleading for its consideration in the work that still remains to be done. And that consideration can only be secured by public opinion; in this country the Board of Agriculture is not expected to give a lead, but it will provide what public opinion may demand, hence I feel justified in asking for the support of a great learned body like the Society of Arts in the appeal we are making, not only for the needs of our own institution but for agricultural research at large.

SEVENTH ORDINARY MEETING.

Wednesday, January 23, 1907; Sir JOHN WOLFE-BARRY, K.C.B., F.R.S., Vice-President of the Society, in the chair.

The following candidates were proposed for election as members of the Society:—

Bancroft, Augustus Charles, J.P., F.S.I., Stokeshall, Plantain-garden River P.O., Jamaica, British West Indies.
Cooper, Hon. Francis Alfred, C.M.G., M.Inst.C.E., Director of Public Works, Colombo, Ceylon.
Freehill, Colonel Francis Bede, M.A., Martin-place, Sydney, New South Wales, Australia.
Gordon, Walter, P.O. Box 96, Harrismith, Orange River Colony, South Africa.
Ikébé, Kichitaro, The Tokyo Asahi Shimbun, 4, Takiyama-cho, Kyobashi-ku, Tokyo, Japan.
Rich, William, Trevu, Camborne, Cornwall.
Smith, Milton W., 413, Failing-building, Portland, Oregon, U.S.A.

The following candidates were balloted for and duly elected members of the Society:—

Baltischwiler, E., Hotel Central, Zurich, Switzerland.
Chambers, Alexander George, 8, Khersonskaja, Onlitsa, St. Petersburg, Russia.
Hobsbaum, Isaac Berkwood, F.C.S., 79, Claremont-road, Forest-gate, E.
Ijuin, Admiral Goro, I.J.N., The Admiralty, Tokio, Japan.
Kerr, George A., Lynchburg, Virginia, U.S.A.
Newman, Arthur D., Messrs. Fraser and Chalmers, Limited, P.O. Box 619, Johannesburg, Transvaal, South Africa.
Trimmer, Lieut.-Col. Augustus Richard, Parkstone, Beckenham, Kent.
Walker, Captain Herbert Marriott, 228, Mackenzie-road, Beckenham, Kent.
Wyllie, Lieut.-Col. Sir William H. Curzon, K.C.I.E., M.V.O., 10, Onslow-square, S.W.

The paper read was—

THE PANAMA CANAL—THE "LOCK CANAL" TYPE AND THE "STRAITS OF PANAMA" TYPE.

By PHILIPPE BUNAU-VARILLA.

PART I.

THE SYSTEM OF CONSTRUCTION OF THE STRAITS.

When Charles V., in 1523, sent from Valladolid to Fernando Cortez the order to search out carefully on the east and west coasts of the New Spain the solution of the "Secret of the Straits" (*el Secreto del Estrecho*), he opened up the great question which has been pending before humanity until our time. I hope to have the honour of making it evident to your minds: first, that this great secret is now discovered; secondly, that its principles were found about the year 1887, during the period when the old Panama Canal Company was at work; and thirdly, that science possessing henceforth all the solutions and all the practical elements necessary, the realization of veritable "Straits" between the Atlantic and the Pacific will take place, and that the work now being carried on by the Americans is only the preliminary phase of this great undertaking.

This secret that Fernando Cortez and his successors believed they would find in a line of fracture concealed between the two continental masses, resided in reality, not in the natural geography, but in the natural topography and hydraulics of the American Isthmus; not in disposition of its ground alone, but in the disposition of its waters and of its ground. Nature has certainly united the two continents together, but it has provided the connection with a hydraulic power such as it is only necessary to harness properly to allow it to displace the mass which obstructs the communication between the oceans, and to transport this mass into spaces which appear to be reserved and ready to receive it.

Definition of the "Straits."—Let us first give a few definitions so that our mind may be clear on this subject. What are we to understand by "Straits of Panama"? How does this new conception of the inter-oceanic water-way differ from the sea-level canal, the construction of which was undertaken in 1881 by Mr. de Lesseps, or from the sea-level canal as it was conceived by the American Government and the Isthmian Canal Commission, and submitted by that last body to the International Board of Consulting Engineers assembled in September 1905 by President Roosevelt at Washington?

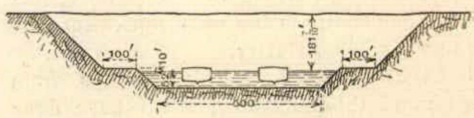
The sea-level canal of M. de Lesseps and that of the Isthmian Canal Commission were both canals with an invariable level, communicating freely with the Atlantic (the tides of which at Colon are insignificant—30 centimetres, or about 1 foot) and closed on the Pacific by locks. These locks prevent the Pacific tides (which attain 3 metres, or 10 feet) from penetrating into the canal, and from producing therein currents which might interfere with navigation. These two projects of a sea-level canal are similarly disposed in plan; the dimensions of their cross section only differ.

M. de Lesseps' sea-level canal had 9 metres ($29\frac{1}{2}$ feet) depth of water, 22 metres ($72\frac{1}{10}$ feet) width at the bottom, and 40 metres (131 feet) width at the water line.

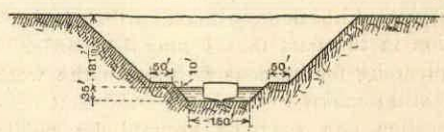
The sea-level canal of the Isthmian Canal Commission had 35 feet (10·67 metres) depth of water, 150 feet (45·75 metres) width at the bottom, and 220 feet (67·10 metres) width at the water line.

The water-way which I called the "Straits of Panama" when I submitted it to the Consulting Board in September 1905, is free of all locks. It communicates freely with the Atlantic and the Pacific. It is 500 feet (152·50 metres) wide at the bottom; 45 feet (13·75 metres) deep at the lowest tides, and its average breadth is 600 feet (183 metres) at the water line. It may be said, in round figures, that this new water-way would be three times broader and one-fourth deeper than the widest and deepest canal ever conceived across the Isthmus of Panama. It may also be said that its breadth, which is about equal to that of the Thames at London-bridge at low tide, is three times less than that of the Bosphorus at Hussein Pacha and at Kawak.

It is a water-way, the dimensions of which are exactly intermediary between those of a natural Straits like the Bosphorus and those of the widest artificial roads planned. It is a water-way of a width similar to those of the great navigable rivers. Strictly speaking one has the right to call such a water-way "Straits" as well as "Canal." (See explanatory note of Fig. J. in appendix, page 273.)



Straits of Panama (*Bunau-Varilla Plan,* 1905.)



Sea Level Canal (*Isthmian Commission's Plan,* 1905.)

FIG. J.—COMPARATIVE CROSS SECTIONS.

I selected the first appellation in order to characterise the suppression of all artificial work, such as tide locks, with which the plans of the Panama sea-level canals have always been encumbered, and in order also to characterise the absolute liberty of navigation and of crossing which the ships will enjoy. Because of the great width and of the great depth given to the "Straits of Panama," it deserves an appellation which recalls the natural not the artificial navigable channels.

Tidal Currents and Currents of Fluvial Water in the "Straits of Panama."—At the simple announcement of a free inter-oceanic communication a preliminary question rises in all minds. Is it possible? Is there not a difference of level between the oceans which makes irrealisable such an open communication? My immediate reply is: No, there is no appreciable difference between the average level of the two oceans, but, as I have already said, the Pacific at Panama has tides which make it rise 3 metres (10 feet) and cause it to descend 3 metres below the average level. On the other hand, the Atlantic at Colon has no tides worth mentioning. Variations of level from 30 centimetres (1 foot) above or below the average level—that is all that has been observed. This being laid down another question arises which has often been answered carelessly in the negative. Will not the periodical variations of level of the Pacific cause currents in the canal incompatible with navigation?

The same question was raised about Suez a long time ago. The Red Sea at Suez has tides like the Pacific, but about one-third the amplitude of the Pacific tides. At a distance from the Red Sea equal to about also one-third of the distance between the Pacific and the Atlantic is a vast surface of water—the Bitter Lakes. They have an almost invariable level like the Atlantic. On the Suez Canal, therefore, the same conditions which are found at Panama are reproduced on a scale of one-third.

In 1856, Lieussou, a member of the Naval Hydrographic Engineers Corps of France, calculated that the maximum of the flood current between the Red Sea and the Bitter Lakes would be 1·16 metre per second and the maximum of the ebb current would be 0·97 metre per second. This calculation, formulated thirteen years before the inauguration of the Suez Canal, was almost rigorously confirmed by experience. After many years it was established that the maximum flood current was 1·20 metre per second, and the maximum ebb current, was 1·1 metre per second. Between theory and experience there was, therefore, only a difference of eight hundredths of one knot for the flood and twenty-five hundredths of one knot for the ebb currents. This proves what degree of confidence we may have in such calculations.

The slope between the Atlantic and the Pacific at high or low tide being about the same as between the Bitter Lakes and the Red Sea at high or low tide, the tidal currents must be about the same in the two cases. A Commission of the Academy of Sciences of France calculated these currents for Panama. (Report of the Academy, May 31, 1887.) The maximum calculated for the current was 1·17 metre per second, that is 2·27 knots an hour, and this with an exceptional tide of 6·76 metres of amplitude, which can only occur once a year. This current was calculated for a canal with restricted dimensions (about equal to those of the De Lesseps canal), 9 metres in depth (29 feet) at Colon and 11·50 metres ($37\frac{7}{10}$ feet) at Panama, and 21 metres ($69\frac{15}{100}$ feet) in width at the bottom.

If the climate of Panama were as perfectly dry as that of Suez, there would not be a shadow of justification for not admitting for Panama the solution that succeeded so admirably at Suez. The conditions of the fluvial waters is the reason to be invoked as an explanation of the rejection of the free opening with a narrow canal. The only complete solution of the management of fluvial waters of the rainy Isthmus of Panama leads us to admit a direct flowing into the canal of a volume of about 800 cubic metres per second, in case of exceptional swellings of the rivers. Even if we suppose that one-half shall flow into the Atlantic and the other into the Pacific, that would generate an additional current of nearly two knots in the sea-level canal projected by the Isthmian Canal Commission and still more of course in the narrower de Lesseps Canal.

In a canal as narrow and as shallow as the so-called sea-level canal, currents superior to two and a half knots would be inadmissible; we are, therefore, naturally led to increase the section in order to free the vessels from the objectionable action of the cumulated tidal and fluvial currents. Naturally the tidal currents will increase a little with the width and depth of the water-way, but the fluvial currents will decrease much more quickly, exactly in inverse proportion to the wet section of the navigable highway.

If we make again the calculations of the Academy of Sciences and apply them to the dimensions I have quoted above for the "Straits of Panama," we find that for the usual maximum tide of 6 metres of amplitude, the maximum current will be 2·93 knots. As the wet section will be about six times greater than in the sea-level canal of the Isthmian Canal Commission, the flowing into it of 400 cubic metres a second will not produce more than a current of 0·3 knot. We may say then that the maximum current to which vessels will be exposed will not reach 3·3 knots, an absolutely insignificant velocity considering the width of 500 feet (152·50 metres) at the bottom, and the depth varying from 45 feet (13·72 metres) to 65 feet (19·82 metres).

The exceptional tide of the Academy of Sciences, which can only occur once a year, in September, would bring about a maximum velocity of 3·14 knots. If, by an extraordinary coincidence, it should meet with one of these exceptional floods, which requires the flowing during several hours of 400 cubic metres, we should not attain 3 knots and a half. This would probably not occur once in a century and would only last a few hours. We may, therefore, say that the real maximum current will be 3·3 knots.

We see, then, that the precedent of Suez guarantees the certain success of such an undertaking, as far as the currents are concerned. But even without this precedent we should have a right to rely on it implicitly, for I repeat that the "Straits of Panama" will have the dimensions of a very large navigable river, like the Thames or the Seine, flowing like them into a sea that has tides of 6 metres of amplitude. There cannot therefore be currents in the "Straits of Panama" more inconvenient to navigation than those of the Seine or the Thames.

As the maximum currents will occur in the neighbourhood of the Pacific (5 lunar hours after low tide), the question may be asked whether the soil of this region is consistent with the velocity of the water.

On this point there is no reason for alarm; the subsoil through which the bottom of the bed of the Straits will be dug is compact and resisting everywhere. It will be only necessary on the last eight kilometres on the Pacific side to protect the sides of the canal with stone embankments, the upper strata of the soil being soft there. This is an easy as well as inexpensive matter.

It results that no objection can be raised with regard to navigation, against the creation of the "Straits of Panama," that indispensable artery of the commerce of the world, the only route permitting a rapid and free passage in four or five hours, the only form of water-way free from all artificial work, locks or dams, the only one protected from accidents, explosions, destruction (in case of war), or earthquakes.

The Indispensable Tool for the Realisation of the "Straits of Panama"—the Dredge.—It is not sufficient to define the ideal type of communication between the oceans; it must also be practically realisable. Now, with the means generally employed, with those used by the Company presided over by M. de Lesseps during almost the entire duration of its existence, with those employed by the second Panama Company, the new Company, with those that the American Government is employing at the present day, such a conception is radically chimerical.

In the three cases quoted above the organ of excavation is the excavator or steam shovel, rolling on rails; the organ of transportation and dumping of the spoils is the car, rolling on rails. With this method, the method in the dry, the difficulties caused by the diluvian rain, in the preservation of the railroad tracks, are enormous. It is necessary for a relatively feeble production to have a considerable number of workmen in constant attendance. Accidents and running off the rails occur incessantly, because in a vast excavation work the tracks often have to be shifted to follow the terraces. Consequently they can neither be well fixed, nor well ballasted, nor well drained.

These necessities, combined with the brusque and violent tropical rain, the bad quality of the workmanship in that country where depression and fever are rife, and the clayish and slippery nature of the soil of the Isthmus, end in runnings off the rail, in accidents which occur over and over again, and which are the great, the only and the essential difficulty of the excavation of the Panama Canal.

The estimates prepared by the Isthmian Canal Commission, the American official authority entrusted with the execution of the Panama Canal gave, in September 1905, as the cost of the sea-level canal excavated in the dry, the following figure:—321,779,731 dollars, that is £64,355,946 sterling. This valuation comprised 7,000,000 dollars for the tidal locks, and 10,394,794 dollars for the masonry walls at Culebra, an erroneous conception now entirely abandoned.

We may, therefore, say that by overlooking these two elements of the work, the estimated cost of digging a lockless sea-level canal, 35 feet deep and 150 feet wide, was, in 1905, in round figures, 300,000,000 dollars, that is

£60,000,000. These figures were arrived at by the official American Commission after six years of study, and two years of effective work under its own management in the Isthmus.

The length of time for the execution of this canal was estimated at more than twenty years by the Commission in 1901, and in 1905 one may conclude from the documents of the Commission that it allowed twenty-two years. The volume of the excavations to be extracted for the sea-level canal thus conceived, having 35 feet depth below mean level from the origin on the Atlantic to Miraflores, K. 62, and 45 feet depth below mean level from Miraflores to the Pacific end, K. 75, with 150 feet bottom width, lateral slopes of 45° and bermes of 50 feet on each side of the canal at 10 feet above the water, is 205,000,000 cubic yards (156,000,000 cubic metres).

The volume of the navigable highway that I have called the "Straits of Panama," with an average depth of 50 feet below mean tide (45 at Colon, 55 at Panama), the width at the bottom being 500 feet, slopes at 45°, and bermes of 100 feet on each side, is about 600,000,000 cubic yards (457,000,000 cubic metres). The completion of the "Straits" would necessitate, roughly speaking, an outlay three times greater than that of the sea-level canal. According to the Isthmian Canal Commission's own figures, it would be necessary to spend 900,000,000 dollars, that is £180,000,000 sterling, or 4,500,000,000 francs, and to wait about 60 to 70 years to see the first vessel pass through it.

Such figures explain sufficiently why the rational and complete solution of the Panama problem, the opening of a water-way unobstructed by locks, having free openings on the two oceans, sufficiently wide to allow ships to navigate and to pass each other without being inconvenienced by the tidal and fluvial currents, has never been examined or discussed before September, 1905, when I submitted it to the International Consulting Board which met at Washington.

If I acted thus, it was not for the vain satisfaction of fixing a theoretical and chimerical term to the efforts of the engineers. In showing them the enviable and desirable end, I showed at the same time the practical way to reach it.

Since 1879, when the first International Congress was assembled by M. de Lesseps, until 1905, when the last one was assembled by Mr. Roosevelt, all the numerous Commissions by whom the Panama Canal was discussed, have all, without exception, forgotten one thing. This was the most important, the essential question—the mode of execution.

All these Commissions have admitted as implicit truth, as an axiom, that the Panama Canal would be excavated in the dry. They then discussed the maximum and minimum form compatible with this mode of execution from the narrow level canal closed by tidal locks on the Pacific side to the lock canal with a summit level, more or less high, in the centre of the Isthmus. (See Fig. K., p. 244.)

Now this particular mode of execution is not the only one as the various Commissions have thought. The excavation, transportation, and dumping may be effected in the dry, on rails, but it may also be effected on water. The excavation in the dry is not the only mode of excavating—it is also the worse, the more expensive and the poorer one. The defects which exist in temperate regions increase in incredible proportions under the climatological conditions of the Panama Isthmus.

With the excavation by floating dredges, transportation by barges and dumping in deep water, all the Isthmian difficulties vanish as if they had been touched by a magician's hand. (See Fig. M., p. 245.)

There is no more need of an enormous army of workmen, changing every minute some of the tracks, in order to follow the progress of the earthwork. There is no more need for the ceaseless care to be taken with the moveable tracks, which have necessarily poor foundations and cannot be disposed for supporting any heavy traffic. There is no more need for struggling against the sudden tropical floods which bring down on the tracks the mud torn up from the slopes of the cut, submerge them, ruin their foundations or bury them. There is no more need of stopping series of steam-shovels for the frequent runnings off the rails, which these unavoidable conditions of the soil and climate bring about constantly, blocking for whole days communication between the points of loading and points of unloading. There is no more need to struggle against the landslips which stop the excavation work, and when they take place on the lines of communication paralyze, by repercussion, both a considerable plant and a great number of hands. There is no more need to tax one's ingenuity to enable the trains to circulate over the dumping places where the rain causes frequent landslips. There is no more need for hesitation between this Scylla and that Charybdis, which is, either to have heavy trucks and powerful locomo-

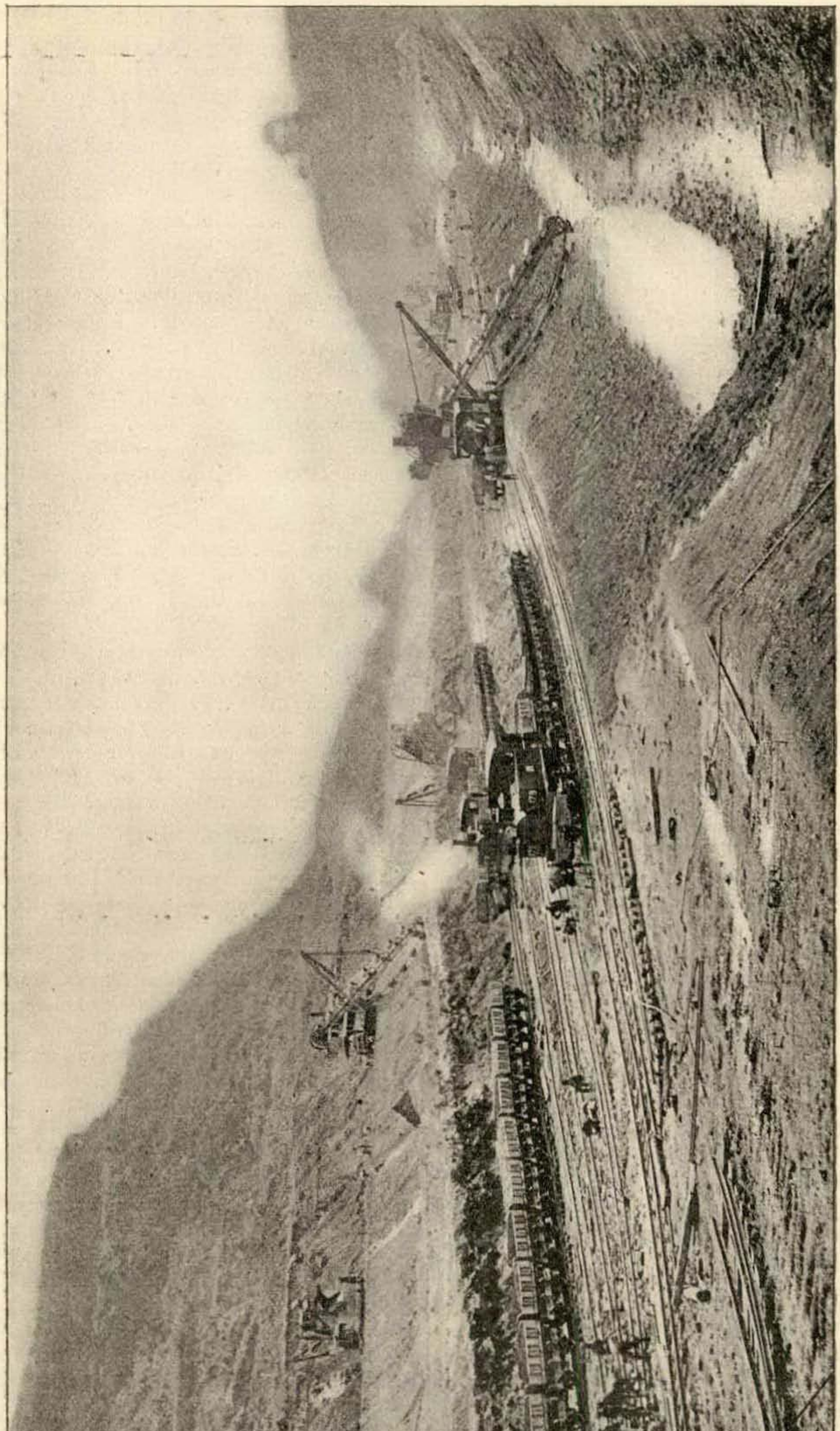


Fig. K.—Works in the Dry (Culebra in 1888). (See Appendix, p. 273.)

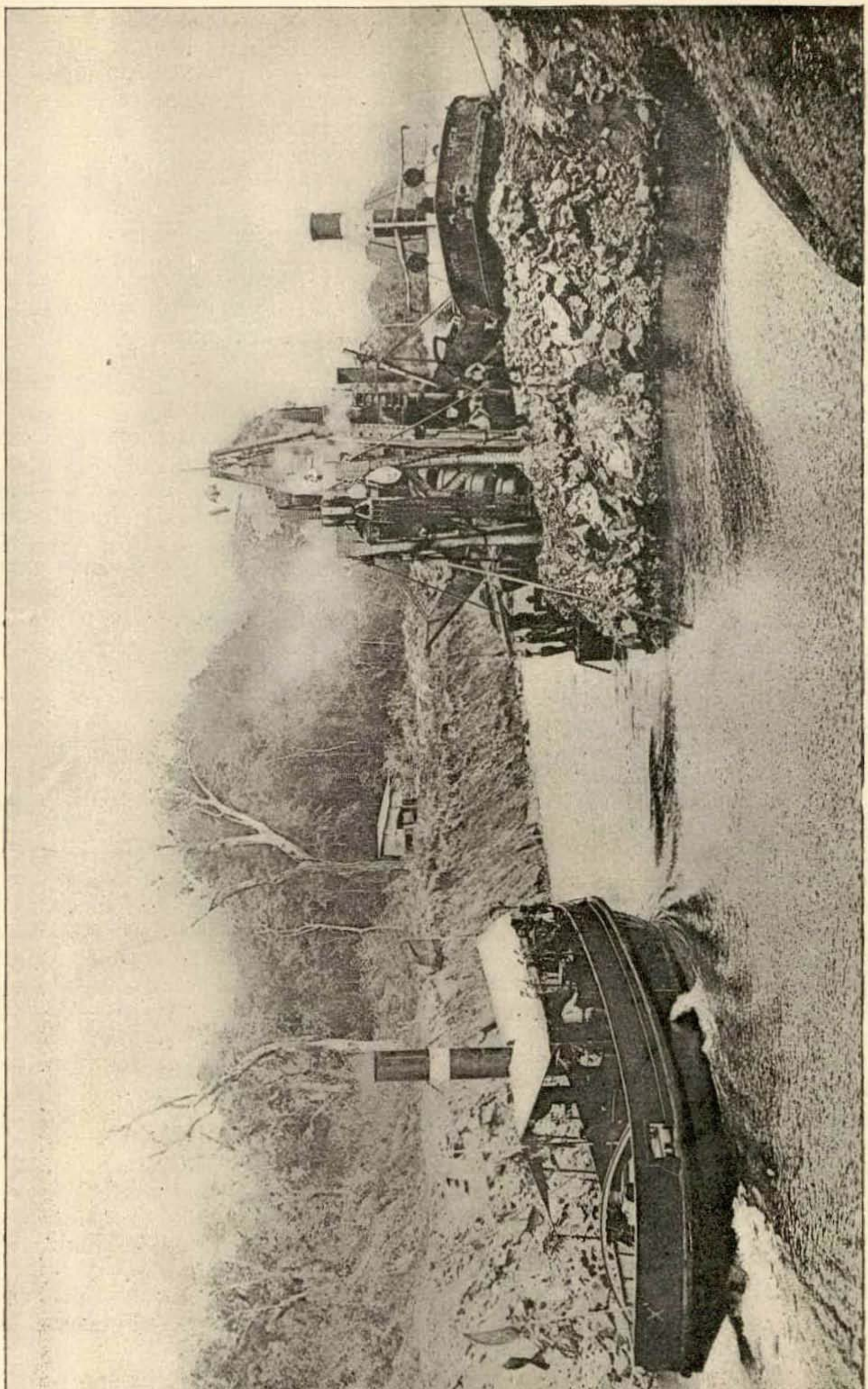


FIG. M.—WORKS IN THE WET (DREDGE WORKING IN BLASTED ROCK—1888). (See Appendix, p. 273.)

tives for excavating huge masses of earth which demands the heavy penalty of more frequent runnings off the rails, so difficult to keep in order, or to have lighter plant circulating more easily, but less powerful and carrying away insufficient masses. There will be no more need of exposing to the alternative sun and rain thousands of workmen who are struggling against nature, and consequently of enduring the sorrowful procession of fevers, and pneumonia which result from this inhuman work.

With the excavation on water by dredges, transportation on water by barges, and dumping into deep water by opening traps at the bottom of the barges, all these difficulties vanish. The carriage power of water is unlimited, and the most powerful organs for excavation may be employed without any drawback. As a matter of fact, dredges with buckets of 1 cubic yard (764 litres), are at present in current use. As there are 15 passing per minute they are capable of bringing up from the bottom more than 22,000 cubic yards in a day of 24 hours.

Making a very liberal allowance for stoppages and other causes of diminution of work, the most pessimistic of dredgers would not figure for one of these instruments on an effective yielding of less than 7,000 cubic yards (5,348 m.c.) measured in the excavation. And dredges of this capacity are not the most powerful ones. There are some in Great Britain which have buckets of about 2 cubic yards (1,528 litres), that is, which can give a useful and practical yield of 14,000 cubic yards (10,700 m.c.) per day, in the most unfavourable circumstances.

With the transport by water a barge can easily carry 2,000 tons of material, that is about 1,000 cubic yards of the heaviest ground (764 m.c.) measured in the excavation, and even more. The number of hands on board a dredge doing this enormous work would be fifteen men if it is a steam dredge, and ten men if it is worked by electricity. On board a barge there would be two or three. The dumping is automatic, and only requires the action of gravity.

All these men live on board the dredge and the barges, protected from the sun and the rain, their only work being to control and watch the machinery—that is, a work without any physical effort. The number of hands is very small; the men are absolutely protected against the inclemency of the weather, just as the plant is itself quite indifferent to rain or sun, night or day.

This admirable and complete solution of all the Isthmian difficulties is reflected naturally in the cost price. I will only mention the figures contained in the report of the International Consulting Board as the result of its inquiries of 1905.

In Appendix K. of the report we find that the excavation, in the dry, of earth and soft rock at Culebra cost for desagregation $11\frac{25}{100}$ cents, that is, $5\frac{5}{8}$d., or $56\frac{25}{100}$ centimes, and that the excavation, transportation, and dumping in the dry cost $60\frac{16}{100}$ cents, or 2s. $5\frac{8}{100}$d., or 3·038 francs, per cubic yard (0·764 m.c.).

In Appendix I. of the same report we find that the excavation by dredge, transportation, and dumping in the sea costs 7 cents, or $3\frac{1}{2}$d., or 35 centimes at Colon, and 8 cents, that is 4d., or 40 centimes, at Panama, per cubic yard (0·764 m.c.) The difference between these two latter prices of 7 and 8 cents. is accounted for by a longer transport in the second case.

It must be noted that the excavation in the dry was made with a new plant bought by the American administration, and that the excavation in the wet was made with the old plant from the first Panama company which had been out of use for 16 years. If the dredges and barges used had been of the power now usual, the prices would have been incontestably about one-half less and reduced, per cubic yard, to 3·75 cents, or $1\frac{7}{8}$d., or 0·185 francs. Mr. Welcker, the Dutch delegate on the International Consulting Board, remarked, in fact, as we see in the Appendix J, that the cost in Holland was 5 cents, or $2\frac{1}{2}$d., or 0·25 francs per cubic metre, including cost of transportation, to 6 or 7 kilometres (4 miles to $4\frac{1}{2}$ miles). This corresponds to 3·75 cents per cubic yard, the price we just named for actual dredging by large steam bucket dredges on a great scale.

Thus we see that the cost price of effective and real works, both in the dry and in the wet, reached by the International Consulting Board, establish a proportion of 1 to 16 between the cost of the excavation work, transport and dumping in the dry on rail and that effected on water in the Panama Isthmus. This enormous disproportion is entirely in harmony with what must be expected from two systems, one of which antagonises all natural forces while the other utilises them.

Gratuitous Electric Power.—But that is not all. The establishment of the dredges, water transport, and dumping is connected, as I will show further on, with the establishment of a dam at Gamboa, across the Chagres, the large river that follows the canal for 27½ miles (44 kilometres) on the Atlantic side. The falls of this dam, erected across the river a little above the point where it enters into the line of the canal, will correspond to a minimum of about 32,000 horse-power, permitting of the free distribution of power to the dredges, barges and instruments for breaking the rock which, by the way, is generally very soft. This electrification of the whole of the great working ground would again allow of an important reduction in the already small cost of dredging and of the transportation of the spoil by water.

Rock-dredging.—The following question might be asked:—However great may be the economy in the excavation of the loose ground by the dredge, is not the removal of the submerged rocks an insurmountable obstacle? We now touch on one of the technical questions ignored singularly enough even by engineers reputed as skilled and competent.

Twenty-five years ago, when I was at the Ecole des Ponts et Chaussées (school for engineers of the government of France), we were taught that this was an operation costing 30 to 35 francs per cubic metre, £1 sterling per cubic yard (1 cubic yard equal 0·764 cubic metre). More recently still we saw the Isthmian Canal Commission including dogmatically (Report of November 16th, 1901) in its list of standard prices, that the extraction of rock under water would cost 4 dollars 75 cents a cubic yard (19 shillings or 23·75 francs). Such exorbitant prices still dwell in the brains of many engineers. In 1885 at Colon, being obliged to remove some submerged rock, I mined it by a process which reduced it to pieces as large as pavement stones and I dredged it afterwards. The dredge did not seem to make any difference between such perfectly broken rock or ordinary sand. This cost me, in spite of the rudimentary method of mining employed, about eight francs per cubic metre, or six francs a cubic yard, that is one-fourth of the price which the Isthmian Commission, composed of the most eminent American engineers, approved sixteen years later; and yet, since my work of 1885, there has been great progress made. Lobnitz, the eminent dredge builder of Renfrew, invented 18 years ago the *derocheuse* (rock destroyer) for the Suez Canal. It consists in a heavy steel chisel ending in a moveable point, which reduces the hardest rocks into pieces the size of a man's head. The heavier the chisel the greater the amount of work accomplished and the less the cost per cubic yard. The weight of the chisel has gradually increased from four to twenty tons. It will certainly reach fifty tons, and then the price of the breaking of rock will be insignificant. Even at the present day the crushing of rocks of average hardness is less than one shilling per cubic yard.

In *Engineering*, August 17th, 1906, there is a note given by Mr. Hunter, chief engineer of the Manchester Ship Canal, stating that the price of crushing rock in the ship canal during ten months work, was less than 9d. per cubic yard, and that in spite of the loss of time due to the passing of vessels. The minimum quantity of work per month was 5,622 cubic yards (4,294 m.c.), the maximum quantity, 10,180 cubic yards (7,778 m.c.), the average quantity, 6,403 cubic yards (4,892 m.c.). The minimum was therefore 225 cubic yards per day. (See Fig. I., p. 248.)

M. Quellennec, Consulting Engineer of the Suez Canal and Member of the Consulting Board, handed over to that body a memorandum stating that the price of crushing rock at Suez was 25 cents per cubic yard by the same Lobnitz method. By one of the most singular and inexplicable omissions, this very important document has never been inserted in the Consulting Board's report, nor in any of the annexes. Neither has any mention been made of the data that Mr. Hunter must have furnished also as a member of the Consulting Board, on the results obtained in the Manchester Canal, later published in *Engineering*, and which are in absolute conformity with those obtained at Suez. These economical results were obtained with chisels of 12 tons at Manchester and 15 tons at Suez.

Comparing the Culebra rock with that of the Manchester Canal, we find that, except in the case of a few dikes, it is infinitely softer than the sandstone of the Manchester Canal. The Manchester price is, therefore, a maximum, and there is no doubt in my mind but that the price of crushing would fall below 11 cents, the present price of mining with explosives in the dry—even if the Lobnitz chisels were worked by steam. The free use of electricity from the Chagres Falls at Gamboa, and the increase of weight in the chisels from 15 to 40 or 50 tons would certainly reduce the crushing to a few pence, surely to less than half the cost registered at Manchester.

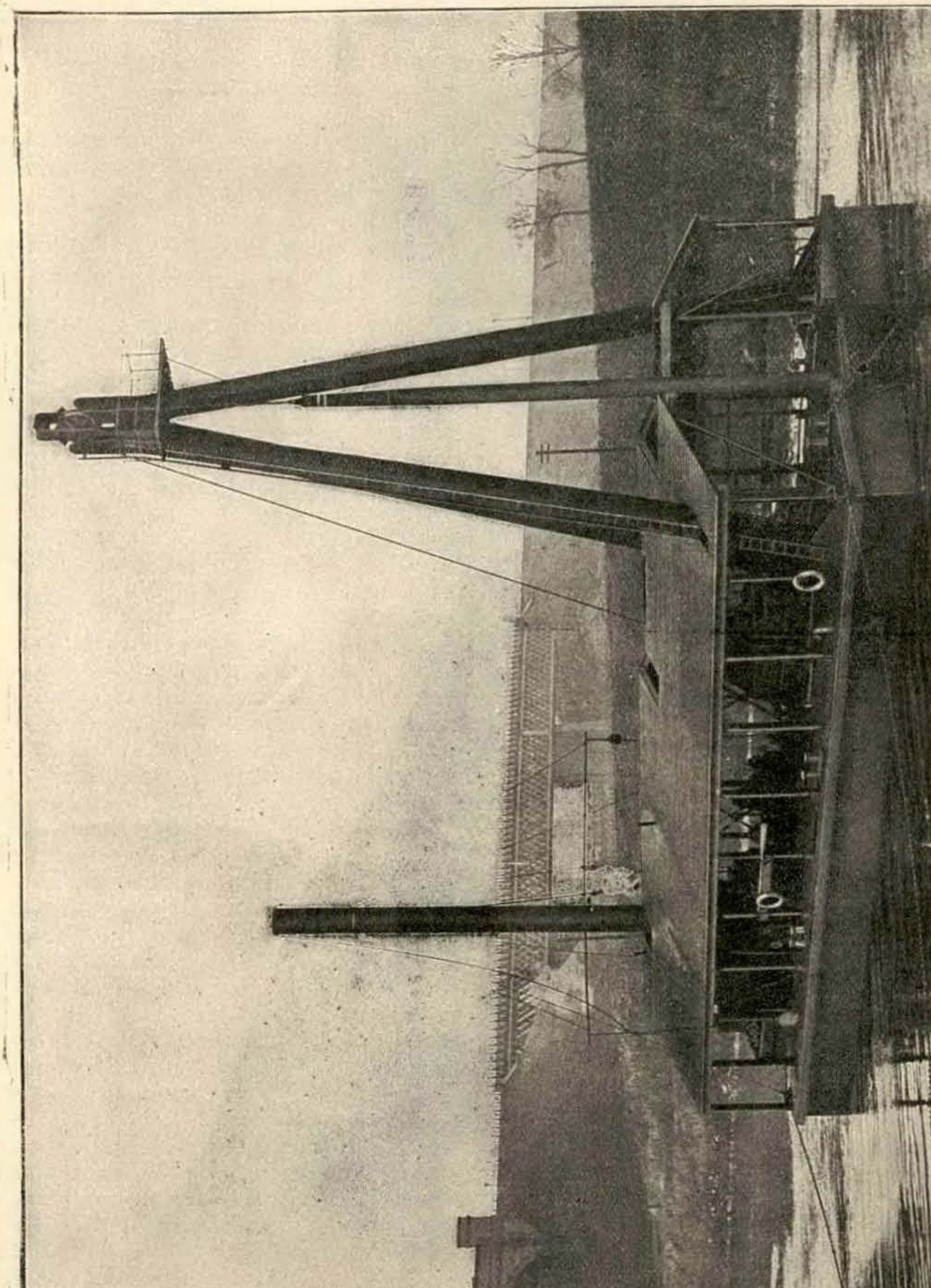


FIG. I.—TWELVE-TON LOBNITZ ROCK CUTTER WORKING IN THE MANCHESTER SHIP CANAL. (See Appendix, p. 273.)

Why did the Consulting Board not insert the memorandum of M. Quellennec, the Consulting Engineer of the Suez Canal, on the real cost price of the crushing of rock at Suez? Why was no mention made in that report of the information that Mr. Hunter, Chief Engineer of the Manchester Canal, must have supplied? There is, in Appendix I. (p. 273), proof that this important information had been given to the Board.

Mr. Wallace, the first engineer in chief of the Panama Canal, appointed by the American Government, said (see p. 380 of the Report):—

"As regards the excavation of submerged rock there is a process which has not been mentioned in any of these reports, but I think that M. Bunau-Varilla has spoken of it; it is the breaking of the rock by what is termed chisel-work.

Mr. Hunter:—You mean the Lobnitz system?

Mr. Wallace:—I do not know what you call it.

Mr. Hunter:—It is perhaps not necessary to dwell on that subject. We have discussed it at length here. It is a proceeding with which M. Quellennec and myself happen to be both extremely familiar."

The silence of the Board in this report on the facts that the two eminent engineers of the Manchester and Suez Canals must have supplied, is all the more suspicious as the price adopted by it for the excavation of submerged rock is 2½ dols., that is ten shillings, or 12·50 francs, per cubic yard; whereas according to the figures for the crushing given by the English delegate, Mr. Hunter, in the *Engineering*, the maximum price of rock breaking ought to have been 18 cents American money), and the price of subsequent dredging ought to have been the one supplied by the Dutch delegate, Mr. Welcker, 3¾ cents (American money). The price of the removal of rock under water ought then to have been fixed by the Board not at 10s. a cubic yard, but at 10¾d., that is to say, at a price more than ten times smaller. And even such a low price ought to have been considered as a maximum on account of the economy that will arise from the use of the free electric energy from the Gamboa lake, for supplying motor power to the dredges, to the Lobnitz rock crushers, and to the barges used for transport. It could, therefore, be expected to be brought down to 7½ pence per cubic yard in the average Culebra rock. The Consulting Board preferred to this logical and experimental price the arbitrary one of 10 shillings.

We may now sum up this exposition of the advantages of the method of dredging substituted for the method in the dry, by saying that it is 16 times more economical when the ground does not necessitate preliminary desagregation. If the ground necessitates such preparation, the crushing by the Lobnitz process, in the wet method, costs less than mining in the open air by the dry method. Such is the scientific truth which results from the experience of great hydraulic undertakings pursued at Suez, Manchester, and a number of other places. I do not hesitate to say that this figure of 11 cents, or fivepence halfpenny, or 0·55 francs, which I consider a maximum for the desagregation of the Culebra rock by heavy chisels of 40 to 50 tons, worked by electricity, and which may appear bold, will appear less so when we consider that the Japanese at Okasaki and at Yokohama, in a soft rock just like that of Culebra, with small Lobnitz chisels worked by steam, spent about four times less per cubic yard.

In the account I gave in September, 1905, before the Consulting Board, of the "Straits of Panama," I did not want to go to the extreme with regard to the advantages of the system of excavation by water, and I limited myself to asking that it should be admitted that it was three times more powerful, and three times more economical on an average, than work in the dry, whilst it really is 16 times more so in a loose soil, and 4 times more so in a rocky soil. I thought that this extreme moderation would permit of an easier approval of my proposal. This humble proposition sufficed, in any case, to prove that it would not cost more money or more time to make the "Straits of Panama" by dredging, than to make the narrow sea-level canal closed by tidal locks with excavators in the dry. But this moderation on my part did not disarm the incoercible partisans of the working in the dry. The system was rejected by the Consulting Board. They could not be convinced either by the grandeur of the end that could be reached or by the evidence of figures collected by the Board itself as to the cheapness, practicability and power of the new method.

Erroneous Arguments Invoked for Rejecting the Dredging Method without which the "Straits of Panama" are Chimerical.—The Consulting Board was content to pass over in silence the eloquent figures relating to the extraction of the rock under water in the Manchester and Suez Canals, and adopted a unit price ten times higher than that resulting from these experiences. This allowed the Board to condemn the method proposed.

This is what we find on page 32 of the report of the majority of the Consulting Board, signed by Messrs. Geo. W. Davis, W. Barclay Parsons, and Wm. H. Burr, Delegates of the American Government; Mr. Henry Hunter, Delegate of the English Government; Eugen Tincauzer, Delegate of the German Government; and J. W. Welcker, Delegate of the Dutch Government and Kellennec, Chief Engineer of the Suez Canal:—

"The claim made by M. Bunau-Varilla that the excavation can be done at low cost rests mainly on the expectation that by the use of electric power, developed at the Gamboa dam and distributed along the line, the expense for fuel for generating steam will be eliminated, and the cost of all mechanical operations reduced by what appears to the Board to be a much exaggerated estimate of the economies thus affected, and on the further expectation that excavation can be made at very much less cost by dredging than in the dry. This reduced cost of dredging is probably true for sand, clay, and other materials that can be moved without being shattered by some preliminary process, but nearly all the materials to be dredged for the transformation are classified in the Board's estimates as rock, and will have to be loosened by blasting under water, by breaking or pulverising—as in the Lobnitz method—or by such other methods as may be devised. Moreover, it must be remembered that the greater part of the dredging is to be done under 40 to 50 feet of water, which will add much to the cost. The unit prices adopted by the Board represent its best judgment in regard to the cost of excavating the several classes of materials which the transformation would require, with the best methods and appliances now in use."

It is hardly necessary to point out the fundamental errors which this paragraph contains:—1. In a dredge where the motive power is free, it is of no importance whatever whether dredging takes place at 20 or 50 feet. 2. It is absolutely false to state that almost all the material to be excavated is rock. The Isthmian Commission admitted that there was about one quarter soft rock, one quarter hard rock, one half earth in the canal (outside of the maritime sections)—that is, from kilometre 24 to kilometre 62. The person who drew up this part of the report evidently considered it necessary to make this assertion, which is so contrary to all material facts, in order to increase the importance of the illusory objections drawn from the false price of excavating rock under water. This erroneous assertion harmonises with the adoption of the ten times too high and prohibitive price of 2·50 dollars for rock excavation, and with the suppression of the information of Messrs. Quellennec and Hunter regarding the veritable prices established at Suez and Manchester. Thus, the necessary system of the substitution of the dredge for the steam-shovel was condemned in 1905 for this imaginary reason: "The ground is too hard."

The first Commission formed after the failure of the old company had also come to the same conclusions, and in 1890 had condemned the dredging system that I had installed in the centre of the Isthmus on both sides of the higher part of the Culebra cut. I had, in fact, inaugurated the dredging of the Culebra cut at the end of 1888, but the dredging work was interrupted in its commencement by the financial crisis, which paralysed the completion of the canal. The Commission, consisting of well-known technical authorities, in 1890, also condemned this method, but this time it was for a contrary reason to that which in 1905 was brought forward by the Consulting Board.

"The idea of turning the principal enemy—water—into an auxiliary is certainly ingenious," said the Commission of 1890, "but it is impossible, the ground is too soft. Perhaps the idea may be taken up later when the harder ground below is reached." Reasons are never wanting to a judge who is anxious to condemn.

Is it also necessary, in order to show the nature of the objections raised by the Consulting Board, to call attention to the fact that, in their report they have inverted the two factors of the economy that the system which I proposed will realise.

The report represents the employment of the free electric power from the falls of the Gamboa lake as the principal element from which I expect to derive economy, while in reality it is only the secondary element. It presents further as a subordinate element what I presented as the keystone of the system of construction, its principal and essential element: the substitution of work on the water for work in the dry. The "Straits of Panama" cannot be made except by dredging, but whether the electricity is free or not means simply the difference between the cost of 24,000 horse-power during ten years generated at a steam central station, and the cost of harnessing waterfalls giving 48,000 horse-power.

Admirable Conditions Presented by Nature for the Employment of the System of Excavation on Water.—After having shown the natural privilege of the dredging method, to the brilliant qualities of which its enemies have not been able to oppose anything but an illogical and baseless condemnation, I will now show with what marvellous perfection it can be adapted to the present conditions of the Isthmus.

If we cast a glance over the profile in length of the natural ground we find three quite distinct zones:—(See Fig. B. or D. or E. in the Supplement and Explanatory note in Appendix, pp. 270-272.)

1. The central mass extending from K. 46 to K. 57 (mile 28·38 to mile 35·42).

2. The high valleys of the Chagres and of the Rio Grande, K. 24 to K. 46 (mile 14·90 to mile 28·58) on the Atlantic side, and K. 57 to K. 62 (mile 35·42 to mile 38 53) on the Pacific side.

Lastly, the low valleys, the maritime sections of the two rivers, the parts where the bottom of their bed is below the average level of the sea. They extend, on the Atlantic side, from K. 0 to K. 24 (mile 0 to mile 14·90), and on the Pacific side from K. 62 to K. 75 (mile 38·53 to mile 46·62).

The elevatlon of the ground on the axis is on an average on the total length (75 kilometres or 46·62 miles) 14 metres 55 ($47\frac{7}{10}$ feet) above the average level of the oceans, but this altitude of the ground varies considerably in the three natural groups that I have mentioned.

In the central mass the average elevation is 181·7 feet (55·43 metres); the maximum elevation of the ground on the axis is 333 feet (101·66 metres), it is 149·4 feet (47·57 metres) at the beginning of the section K. 46, and 110·7 feet (33·78 metres) at the end of this section K. 57.

Between the maritime part, Atlantic side, and the central mass, that is to say between K. 24 and K. 46, the average altitude is not more than 47·9 feet (14·65 metres). In the corresponding section, that is from K. 57 to K. 62, on the Pacific side, the average altitude is 53·3 feet (16·25 metres). Lastly, in the maritime parts the average altitude falls to 11·9 feet (3·68 metres), on the Atlantic side from K. 0 to K. 24, while on the Pacific side it falls below the average level of the sea and is only −2·3 feet (−0·69 metre).

This glance at the configuration of the Isthmus shows that the heaviest part of the excavation work will have to be done over the 11 kilometres extending between K. 46 and K. 57. In fact, out of the volume of about 205,000,000 cubic yards which would have to be excavated over the 75 kilometres of the canal in order to obtain the sea-level canal of the Isthmian Commission (Project of 1905: 35 feet in depth, 150 feet in width at the bottom, and 50 feet berme), there is not less than 114,000,000 cubic yards or 87,000,000 cubic metres to be extracted from the central mass on the 11 kilometres length. Thus we have more than half the total work concentrated there.

Almost the same may be said in regard to the "Straits of Panama," with its 500 feet of width, its average depth of 50 feet, and its bermes of 100 feet. The straits necessitate an excavation of 600,000 cubic yards (458,000,000 cubic metres). Of this amount 260,000,000 cubic yards (199,000,000 cubic metres) must be excavated from the 11 kilometres of the central mass. In this case it is not quite the half of the total excavation, but about four-ninths.

The Gamboa Lake and its part in the Excavation of the Straits.—If we glance at the map of the Isthmus we shall see that the Chagres, the principal river of the Isthmus, enters the line of the canal at K. 45 (27·96 miles). (See Fig. C, p. 252.) Just above this point the river passes between two mountains, the Cerro Obispo and the Cerro Santo Cruz, both formed by a hard and homogenous pudding stone. The rocky slopes of the two mountains meet under the bed of the Chagres, about eleven metres lower than this bed, or in other words, at the sea level. The whole, when cleared of sediment and soft rock, forms a sort of V, about 500 feet (150 metres) wide at the bottom, and with an opening of about 2,250 feet or 675 metres at an altitude of 160 feet (48 metres) above the sea level. This is an admirable site for a masonry dam. Only the foundations would have to cross a layer of 11 to 14 metres of alluvium, over which the river flows. This part can be made either by pumping the water from the excavations or by using compressed air.

The old Panama Company had planned a dam at this place in order to control the floods of the Chagres by the formation of a regulating lake, the maximum elevation of which was to be also 60 metres above sea level. By an almost incredible error, the new Panama Company had, without any plausible reason, abandoned this perfect site and transported to Alhajuela, 16 kilometres (10 miles) higher in the valley, the dam which it was intended to construct there.

The Isthmian Canal Commission, in its

dry, is not to be considered optimistic. With the dredges — and especially the electric dredges—the delays would be reduced to a strict minimum and the yielding which we have admitted for the dredges, allows a margin of security equal to the figure itself. Neither can we admit that the work to be executed, in addition to that of the main cut, might delay the term fixed for the end of the undertaking. In fact, in the maritime parts of the Isthmus, between Colon and K. 24, on the Atlantic, and between K. 62 and Panama, on the Pacific side, the ground would be excavated and then transported to the sea or pumped and deposited by water on the banks of the valley. (Excavation on the maritime section of the Atlantic side, 87,000,000 cubic yards; excavation on the maritime section of the Pacific side, 37,000,000 cubic yards.) As regards the sections comprised between the maritime parts and the main cut, they would be dredged like the preceding ones, and the material would go into the Lake of Gamboa.

When the level of the water will have descended from 170 feet to an altitude of 60 feet in the main cut, dams across the Rio Grande and the Chagres will spread to this same level the sheet of water from K. 24 to K. 62. New dredges would be operated, independently of the others in these sections, and the spoil from them would be thrown into the Lake of Gamboa, either by transportation through the locks or by pumping them into the lake. Of course a part of the spoil could be also in these sections deposited or pumped on the sides of the valleys, and the work of dredging begun before the dredging level in the Culebra cut is lowered to 60 feet elevation. (Excavation from K. 24 to K. 46—170,000,000 cubic yards in the Chagres Valley. Excavation from K. 57 to K 62—45,000,000 cubic yards in the Rio Grande Valley.) At this period, the point of access for the barges to the Lake of Gamboa, the foot of the flight of locks being near K. 46, will be about the middle of the long dredging summit extending from K. 24 to K. 62. It would be at about three kilometres (two miles) from the mathematical centre of this summit. In this manner the average of the distance to be gone over in the dredging summit, which was $5\frac{1}{2}$ kilometres in the first phase, will be 11 kilometres in the second. It will be, therefore, very small during the whole period of excavation.

Nature of the Ground in the Culebra Cut.—The mass of the Culebra cut is composed, through almost its entire length, of hard clay, which barely deserves the name of rock. The Isthmian Canal Commission, in their report of 1901, have given a very accurate definition of the nature of the rock:—

"There is a little very hard rock at the eastern end of this section (Culebra), and the western two miles are in ordinary material. The remainder consists of a hard, indurated clay with some softer material at the top and some strata and dikes of hard rock. In fixing the price it has been rated as soft rock, but it must be given slopes equivalent to those in earth. . . . . Probably nine-tenths of the material would naturally be classed as hard clay of stable character."

If we admit that the average hardness is that of the sandstone of the Manchester Canal, we shall make an estimate probably two or three times too high, surely double.

Quantity of Hydraulic Power Necessary.—As we have seen already, the figures furnished by Mr. Hunter, Chief Engineer of the Manchester Ship Canal, and published in *Engineering* of August 17th, 1906, establish the fact that the minimum amount of rock broken, with a 12 tons cutter, was 225 cubic yards per day, with two shifts working ten hours each, which corresponds to about 270 cubic yards for a 24 hours' work with three shifts of men. Let us admit the extreme minimum of 200 cubic yards per day. Therefore, if the $\frac{9}{10}$ths of the whole of the Culebra cut, instead of being hard clay scarcely fit to be called soft rock, were of the hardness of the average Manchester rock, it would require 500 rock cutters of 12 tons to disintegrate and make dredgable 100,000 cubic yards per day. But, as we have said, owing to the softness of the Culebra rock, the Lobnitz rock cutters will on an average yield three times as much. If, for safety, we reckon only twice, we should be led to say that 83 pontoons with three rock cutters of 12 tons on board would do the work. As the cutters are raised about 10 feet (3·05 metres) every 15 seconds, it would require a mechanical power of 32 horse-power per cutter, that is 8,000 horse-power for the whole, which, reckoning only 50 per cent. for the yielding, will correspond to 16,000 horse-power at the falls generating the power. The results would be considerably improved by increasing the weight of the cutters from 12 to 40 or 50 tons, but we will not take this into account so as not to base our calculations on experiments yet to be made.

The dredging would be made by 16 electric bucket dredges, every dredge having five barges carrying 2,000 tons for the transportation and disposal of the spoil. These barges would be supplied with propelling electric apparatus of 50 horse-power. Reckoning an average employment of 200 horse-power for each dredge, and 200 horse-power for the five barges, the extraction and the transport would also require 8,000 horse-power.

The whole of the operations of the works on the central mass, K. 46 to K. 57, will, therefore, necessitate a fall of water of 32,000 horse-power. The works to be made on the sides of the central mass from K. 24 to K. 46 and from K. 57 to K. 62, will require the assistance of naval plant of equal power but without Lobnitz rock cutters, and this will demand a new hydraulic power of 16,000 horse-power, that is 48,000 horse-power in all. The whole of these requirements will be assured by the falls of the Gamboa and Bohio Lakes.

The average supply from the Chagres at Gamboa, according to the regular returns made during a period extending over more than the last 20 years, is 100 cubic metres per second, but during the three months of dry season it falls much lower than the average.

The volume of the Gamboa Lake comprised between the elevation 170 feet (51·85 metres) and elevation 200 feet (61 metres) is 877,668,000 cubic metres. If the lake is full at the end of the rainy season, it can supply during more than 100 days 100 cubic metres a second, without falling below the level of 170 feet, and without receiving any water from the upper valley. This reserve thus ensures the constancy of the average supply during the dryest period.

As 30 cubic metres per second will be required for the working of the locks giving access to the lake when the dredging is in progress, between K. 24 and K. 62, 70 cubic metres would remain free for the generation of power. The Gamboa fall should be reckoned between the maximum level of the Bohio Lake (60 feet) and the minimum level of the Gamboa Lake (170 feet), that is, 110 feet (33·55 metres). The hydraulic power, therefore, is 31,200 horse-power. It is therefore practically equal, under the worst conditions, to the demands of the excavation of the central mass.

On the other hand, at Bohio, we will have at our disposal a minimum of 100 cubic metres running from Gamboa, and, on an average, of 150 cubic metres a second.

The supply of 100 cubic metres, falling from the minimum height of the Bohio Lake (50 feet or 15·25 metres), will produce 20,000 horse-power. The minimum total power developed will be, therefore, more than 50,000 horse-power during the period of the lowest waters, and will satisfy the requirement of 48,000 horse-power necessary for the work outside of the maritime parts. This latter work will be carried out by steam power; the spoils will be transported into the sea or pumped on to the valley sides.

Amount of Men and Money necessary.—After noting that Nature has placed exactly at the desired spot the necessary mechanical powers for this gigantic displacement of masses, let us see how few men are necessary to direct this power in order to attain the end in view. The working of the central mass will require 16 electric dredges worked by 10 men, 85 pontoons worked by 9 men, 5 barges for each electric automotor dredge, each worked by 2 men. This makes an effective force of 1,067 men, and with three gangs at work, 3,201 men per day, or 3,500 men if we include the staff of electricians, men at the locks and the workmen who are attending to repairs, &c. This force will be increased by 1,000 men when the valleys of the Chagres and the Rio Grande are attacked, for in these regions the almost complete totality of the ground is loose and directly dredgable. The immense work to be carried out between K. 24 and K. 62 only demands, therefore, a force of from 3,500 to 4,500 men, that is an average of 4,000 men.

As is necessary in tropical countries, instead of repairs made at the shops new pieces will take the place of those out of order, and repairs on the spot will be reduced to a minimum. Admitting the excessively high average salary of 12 shillings, that is 15 francs, or 3 dollars, per day of eight hours, so as to include in this amount the expenses of the superior technical management, the daily expense would be 2,400 pounds sterling, or 12,000 dollars, or 60,000 francs; that is, for 300 days of work a year, an annual expenditure of 720,000 pounds sterling, or 3,600,000 dollars, or 18,000,000 francs.

The expense in ten years and a-half would be 7,560,000 pounds sterling, or 37,800,000 dollars, or 189,000,000 francs for the work exclusive of the maritime parts	£7,560,000
If we add—	
1. An equal amount for repair pieces	£7,560,000
2. A sum of £5,000,000 for construction of the locks giving access to the Lake of Gamboa, the Gamboa dam (this latter work was valued at £1,000,000 by the	

Isthmian Canal Commission), the smaller accessory dams, the electric installations, &c.	£5,000,000
3. A sum of £2,000,000 for the excavations to be made in the maritime parts of the Isthmus, K. 0 to K. 24 and K. 62 to K. 75	£2,000,000
4. A sum of £4,000,000 for the dredging, transporting, and rock-crushing plant	£4,000,000
5. A sum of £2,400,000 for surplus expenditure pertaining to the excavation of the part of the Culebra cut above 170 feet of altitude	£2,400,000
We reach a total of	£28,520,000
and by adding for unforeseen contingencies	£1,480,000
we obtain the total above-mentioned of	£30,000,000

or 150,000,000 dollars, or 750,000,000 francs.

The mere statement of the elementary figures shows what a considerable margin exists between the valuation and the probable reality. I have the firm conviction that the total expense will not reach two-thirds of this amount, and will be limited to twenty million pounds sterling, or 100,000,000 dols., or 500,000,000 francs, that is one-ninth of what the execution of this gigantic conception would cost in the dry. Those who have a less optimistic view about the cost of dredging operations may double or even treble the cost of labour and repair pieces. They will not reach more than £60,000,000, a still perfectly admissible sum for such a result. It is this over-conservative estimate of £60,000,000 which I gave to the Consulting Board in 1905.

After having shown how the rational utilisation of the topography and the dynamics of the Isthmus allow of the easy and low priced execution of the hitherto chimerical work of the creation of a Straits across the Isthmus of Panama, let us examine what this magnificent road would be when once brought into existence.

Management of the River Floods.—The three large rivers of the Isthmus are the Chagres and its two large tributaries, the Rio Trinidad on the left and the Rio Gatun on the right. They fall in the Chagres between Bohio and the sea. The Chagres, domesticated by the lake formed by the Gamboa dam, would have no more alarming floods and would empty into the Straits the pure lake water. The highest floods measured at Gamboa during a quarter of a century have risen to 1,600 cubic metres a second; the lowest water noted corresponds to a supply of 11 cubic metres per second.

There was a flood in 1879, which is said to have risen to 2,040 cubic metres per second at Gamboa, but it was not measured and is a mere conjecture. The duration of the rise of the floods is short and lasts at the most 48 to 72 hours. Caused by the passage of a cyclone they disappear with it. The total of the mass of water delivered by the Chagres at the rate of 1,600 cubic metres per second, in 48 hours continuously, is 276,000,000 cubic metres. It must be considered as a practical maximum of exceptional flood. If nothing flows off into the Straits, it corresponds to a variation of the lake level of 2·9 metres, or 9 feet 8 inches.

We have said that the volume of the lake at elevation 200 feet, is about four times the volume of the excavation of the Straits of Panama, which will be dumped into it. It will lose, therefore, by this operation, less than a quarter of its surface, since the spoils will be deposited against the dam in the deepest part of the lake.

These figures show with what facility the control of the Chagres waters will be effected by the Gamboa Lake after the excavation of the Straits. Between K. 24 and K. 44 the Straits will receive direct the waters of the small rivers which will flow into it. Their sediments are slight, like those of the Chagres, and it will be easy to diminish them still more by breaking their slopes by means of small dams. The volume of water supplied by these small rivers rises in these exceptionally short and rare floods to 600 cubic metres per second. Even if we figure on 800 cubic metres per second every three or four years, for 48 hours, the section of the Straits being on an average about 2,500 square metres, this supply will only produce a current of 0·32 metre per second, that is 0·6 knot, if all flows on one side; 0·3 if half goes to the Pacific, and the other half to the Atlantic. Between K. 24 and the sea, the old bed of the Chagres, completed by river diversions which are existing with the exception of one that remains to be opened, will take straight to the sea the waters of the Trinidad, of the Rio Gatun and of the other small tributaries falling between the Atlantic and the kilometre—24. Therefore no contact will exist between those rivers and the Straits in the maritime part of the canal on the Atlantic side.

On the Pacific slope the rivers have insignificant floods and will flow into the Straits direct. Thus the question of the Isthmus rivers is completely solved with the Straits, while with a sea-level canal of narrow section the problem is difficult to meet completely. It has caused a great deal of ink to be spilt, and with reason.

Indestructibility of the Inter-oceanic Passage.—The "Straits of Panama," that unique artery for the world's commerce, must have as its essential quality—indestructibility in case of war and in case of a grave seismic commotion. The "Straits of Panama," with their width of 600 feet (180 metres) at the water level, their bermes of 100 feet (30·50 metres) on each side, defy all land slips. They need no locks, that plague and constant danger of summit level canals, or of sea-level canals with tidal gates. The only work of art which will exist after the opening of the "Straits" will be the Gamboa dam. But after the construction, this dam will, in reality, have disappeared. The hundreds of millions of cubic yards placed in the valley above the dam will have filled the valley for several kilometres, and this huge deposit will form the veritable and indestructible dam that no explosion of dynamite and no earthquake will be able to affect. Some millions of cubic yards of rock dumps will also have buried the lower face of the dam, rendering it inaccessible and immovable. We may say that the "Panama Straits" will not depend on any work of art, and when once made will have neither locks nor dam.

Nature of the Water-way Created.—It will be a veritable natural road of about the width of the Thames (the width of the Thames at low tide at London Bridge, 650 feet); it will be one-third of the width of the Bosphorus, it will be a water-way where ships will be able to navigate freely, crossing each other as in a large maritime river, with plenty of water on their sides or below their keel. The transit will be made in four or five hours.

Such are the characteristics of this artery, so desirable and so easy to realise if technical blindness did not lead a great nation, like America, to an inconceivable negligence of the clearest and most perfectly demonstrated scientific progresses of our days. By persisting, as she does, in turning her back on progress, and exhausting herself in a useless and ridiculous work, American genius does not see that it is now losing a terrible battle.

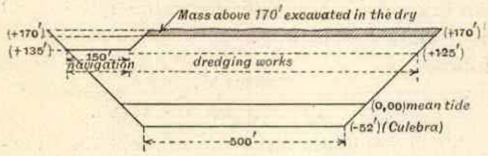
The defeat that reason is suffering now in America will weigh heavily on the prestige that American genius had so justly acquired hitherto. It is abjuring at the present day the very doctrine which had made its fame, the increase of machine power and the decrease of the mechanical action of man. We have every right to err as long as scientific truth has not been revealed, but from that moment, to neglect it, to turn our back on it, is to decline. It is lowering one's self willingly in the intellectual hierarchy of humanity.

PART II.

PROVISIONAL LOCK CANAL.

The complete solution of the problem, otherwise insoluble, of the enormous labour necessitated by the excavation in the dry, of the Panama sea-level Canal; the possibility of creating veritable "Straits," invulnerable in case of war or earthquake, and that, for an expenditure at the utmost equal to the least costly of the lock canals with a summit level—such are not the only consequences of the substitution of the work on the water or the work in the dry. (Estimates of the Isthmian Committee for a lock-canal with 85 feet altitude, 28,800,000 pounds sterling; Report of 1901. Estimates of expenditure for a sea-level canal, 64,400,000 pounds sterling; document of 1905. Estimates for the Straits of Panama, 30,000,000 pounds sterling.) There is another consequence, likewise a most important one.

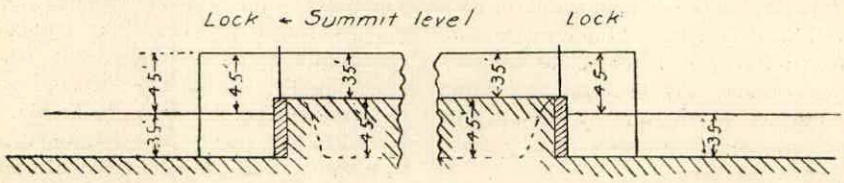
During the four to five years necessary for the construction of the dam at Gamboa:—1. If locks be erected at the extremities of the 11 kilometres of the cut of the central mass, and towards the extremity of the maritime parts of the valleys of the Chagres and of the Rio Grande, at the spot that I have indicated as the limits of the two successive dredging levels. 2. If digging in the dry is continued down to elevation 95 feet (28·97 metres) through the passage already opened across the Culebra down to elevation 157 feet (48 metres), a lock canal with a summit level at 130 feet elevation will have been created without great effort, and in a short space of time, between the oceans and at the same time the dredging basins necessary for the execution of the Straits of Panama. (See Fig. C, p. 252, and Fig. D. in Supplement.) The enormous width of the cut will always allow of housing simultaneously vessels in transit, the Lobnitz lock-cutters and the dredges. The transit demands only a band of 150 feet (45·75 metres) and at 130 feet above the sea, the cut will be six times as broad as that and four times as broad at the sea level. It will suffice to insure navigation, at every depression of the water level, to reserve a channel that will have been previously deepened, in order to afford the necessary water depth, notwithstanding the lowering of the water level. The process is so evident and so easy that it is not necessary to dwell on the subject at any length.

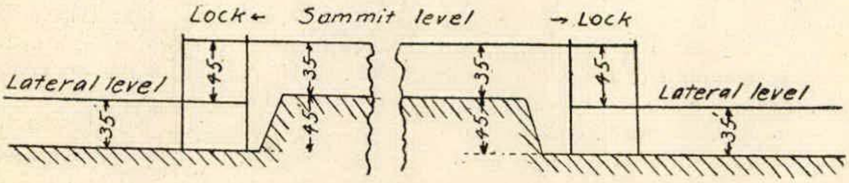


A more serious question remains. What will happen with the locks when the level is lowered? There will be a material impossibility with the usual construction of locks. I have supplied a most simple solution to this problem some twenty years ago. Let us consider a navigable level closed by two locks of the usual type, that is to say, by lock having an upper gate of a height equal to that of the water depth of the level the lock closes, and a lower gate with a height equal to the sum of the water depth and of the fall of the lock.

repeated as many times as is necessary to bring the summit level to the same level as the lateral levels. When the levels of the summit level and the lateral levels are the same, the gates of the lock are taken away. There remains nothing then but the masonry work which is a mass of artificial rock in the new and single summit level, formed by the old summit level and the old lateral levels. This artificial rock is removed as any other rock that is met during the excavation. If the locks are "in flight" by taking dispositions, inspired by the same principle, their gradual elimination is also insured while the transit is going on. It is in this method of construction that the key to the transformation of a lock canal into a sea-level canal resides.

I proposed, in 1887, this method to the old Panama Company in order to secure, in a brief delay, the opening of the canal with locks and to continue later on the excavation of the sea-level canal. I did not then go into the question as far as I am doing to-day. I did not show then the facility for obtaining by this transformation, not only the sea-level canal, but also the "Straits of Panama."





It is evident that with such a lock no lowering of the level is realisable without altering the lock, that is to say, without stopping navigation. But if the upper gate be made with a height equal to that of the lower gate, and if the summit level be deepened on a length of two or three hundred metres above the lock, the entire difficulty vanishes. For instance, one metre of the summit level may be dredged without touching the lock. This deepening accomplished, the level of the water may be lowered one metre without modifying either the circulation of ships or the operation of the lock. This dual operation should be

In those days, only one thing could be guaranteed, namely, that the excavation of the rock of the canal would not cost, if excavated under water, more than in the open air. Now, thanks to the progress made in dredging, thanks to the application of electricity as motor power for the dredges, which I realized for the first time on the River Esla in Spain, in 1895, thanks finally to the progress achieved by the Lobnitz method, in the economic desagregation of rock formation of any hardness, a progress which took place only during the last few years, it is possible to go to the extreme limit of the method and to project the

"Straits of Panama." The great objection to my method of handling the Panama problem has disappeared. The extraction of rock under water already in Europe requires only half the expenditure of its cost in open air. The figures given by the chief engineer of the Manchester Canal, Mr. Hunter, establish it. To the 9d. which the desagregation of the rock costs in the Manchester Canal, if we add 2d. or 3d. for dredging on a large scale, we arrive to a price about half what would cost a similar work in the open air (2s. a cubic yard in the dry). In the Isthmus, this difference increases in enormous proportions on account of the cost and inferior quality of labour, and of the fatal interference of diluvian rains with the works in the dry, especially as far as transport and dumping are concerned, two elements of which the dredging is free.

Opening in Three Years to Limited Shipping or to Military Navigation.— But however rapid the execution of an inter-oceanic passage, at elevation 130 (about four years), this period may be still more shortened, and if, for instance, it was desired to open in three years' time a passage limited to military navigation, it would suffice to add a fifth lock on each side of the Isthmus and to pass in the central cut at an altitude of 170 feet, that is of 52 metres. (See Fig. E. in Supplement.)

The work done by the French companies has, at the present day, opened up a passage at 157 feet, across the central mass, so that it would be sufficient to have only 17 feet excavated on a limited longitude to have the canal bottom at 140 which will give immediate passage. Practically we may say that no excavation of any importance would be necessary in the central mass for that level.

On the other hand, for a lock canal at elevation 170, the erection of the locks may be very much shortened if we limit the masonry to the head of the locks, and if we take the natural slopes of the excavation in their nude state as the lateral walls of the lock, and if we build only one lock instead of turned locks. We would thus reduce to almost nothing the mass of masonry that is necessary for erecting the locks. Of course it would need more water to do the lockages, but this is insignificant—if it is desired to establish military communications only, that is to satisfy a limited traffic.

Finally, whilst constructing the dam at Gamboa, we can, now, provide against the delay of four or five years that it demands, by the installation of pumps to elevate into the summit level the water required for the lockages of the inter-oceanic limited navigation.

One question only remains open in this condensed programme. It consists in the opening of the outlet of the Lake of Bohio. This outlet should be normally made through a saddle between two hills at some distance from the axis of the canal, and may demand two or three years' work. Here, as elsewhere, the problem may be simplified, by making the Chagres flow into the main cut itself, that has been opened for the canal by the old Panama Company. This cut has been excavated through a resisting rocky mass and lowered to 12 metres above the sea. Nothing would be easier than to broaden, in the space of one or two years, this cut, so as to allow the Chagres to flow on the side of the locks installed in the same cut, which will also open up the passage from the Atlantic level to that of the Bohio Lake level.

PART III.

PAST AND PRESENT WORKS AND PROJECTS.

Results of the Work of the French Company.—It will have been seen how the question of opening to traffic may be simplified, if one wants to clear it of an absurd dogmatism and look only at the work to be realised in making use of the great results actually obtained.

The work of the old Panama Company has, in reality, cleared away entirely all the great difficulties of the undertaking. The work of that company has advanced the undertaking to such a point that the rational solution that I have indicated may be applied, and the execution of the "Straits of Panama" may be commenced now with the exclusive employment of natural conditions and natural forces. The work done by that Company if used in a logical way, can allow both the beginning of the construction of the "Straits" and the opening up to traffic, under more or less perfect conditions, according to whether it is decided to devote three years or from four to five years to open the transit. In any case, this premature opening will constitute a most stupendous service to humanity, and the tax of transit will cover entirely the expense involved in the further construction of the "Straits of Panama."

The Fundamental Error of the Consulting Board.—In September, 1905, at Washington, I presented the question of the "Straits of Panama," under a form slightly different from that which I adopt to-day before the Society of Arts. It was then my desire to show that everything converged towards a rapidly constructed lock canal with a high summit level which should be transformed later on into a veritable Straits. As I have already said, this proposition, "the high level lock canal first, the Straits of Panama afterward," did not gain the day with the Consulting Board, which would not hear of the method of excavation by dredges, and maintained, against all theoretical and experimental evidence, the work in the dry.

This great and deplorable error is the same that was the cause of the decision taken by the Congress of 1879, assembled by M. de Lesseps, in Paris, and by all the Commissions that, successively, have studied the Panama problem. But, contrary to what happened in the Congress of 1879, the Consulting Board was placed in presence of the technical solutions which I brought, and which twenty-six years of progress in the realms of science and industry have rendered so productive in striking results.

As the Congress of 1879 had nothing before it but the work in the dry, that body may be excused for not having seen further; the Consulting Board in 1905 had everything before it, and is without excuse for having closed its eyes. It is not without interest, from a philosophical point of view, to note that the same error generated identical consequences at an interval of 26 years.

In 1879, two projects obtained the preference of the Conference, the project favored by M. de Lesseps, the sea-level canal with tidal locks, and the project elaborated by a great French engineer, Godin de Lépinay. The latter consisted of the construction of dams at the two extremities of the Isthmus, one at 10 kilometres from the Atlantic, at Gatun, across the Chagres, and the other across the valley of the Rio Grande, in the proximity of the Pacific. (While indicating Gatun, Godin de Lépinay reserved the question of the practical possibility of a dam there, and selected Bohio, 14 kilometres higher up, in case the Gatun dam should not prove possible.) These dams would keep the waters of all the rivers of the Isthmus, at 24 metres above the sea ($78\frac{7}{10}$ feet), and would constitute an interior lake, making the Isthmus of Panama an artificial Isthmus of Nicaragua.

Twenty-six years later, two projects identical with those of Lesseps and Godin de Lépinay divided the International Consulting Board at Washington in 1905. The majority, composed of three American and five foreign members* voted for the sea-level canal with tidal locks; the minority, composed of five American members, voted for a canal with an interior lake formed by a dam at Gatum. The only modification made in the project of Godin de Lépinay was to substitute to the elevation of 24 metres ($78\frac{7}{10}$ feet), the elevation of 25·90 metres (85 feet) for the altitude of the interior lake. No essential characteristic of the project of Godin de Lépinay was, therefore, modified. Alone, his name remained buried in oblivion. (See Fig. A, p. 261, and Fig. B. in Supplement.)

The report of the minority of the Consulting Board makes no mention of the author of the project that it adopted. But the reports of the Congress of 1879 render him the justice that is due to him. It is the project of Godin de Lépinay that met with the favour of the American Government. And it was his project that it recommended to Congress.

Congress was thus placed between two detestable alternatives. The first was to adopt a shallow, narrow sea-level canal, to be dug in the dry, the construction of which could not be effected in less than 20 years, notwithstanding the affirmations devoid of all experimental basis of the majority of the Consulting Board, who solemnly declared that it would require only from 12 to 13 years. The second alternative was to adopt a canal with perpetual locks. This latter solution was introduced to Congress as the American conception, the type of which is the Sault Sainte Marie Canal, by the President of the United States, in opposition to the European conception of the sea-level canal, the type of which is the Suez Canal.

This view is, of course, erroneous; we know that the first lock canal, with a summit level, was built in France, between the Atlantic Ocean and the Mediterranean, by Riquet, under Louis XIV. We know the two great canals of Manchester and of Kiel are lock canals, and, finally, we know the project adopted was a French project, twenty-six years old.

The nationalist argument did not prevail, however, over the evident disadvantages of this system; the terrible accidents to which any false manœuvre would expose it; the

* Majority:—Messrs. George Davis, Barclay Parsons, W. H. Burr (American members); Messrs. W. Henry Hunter, A. D. Guérard, Eugen Tincauzer, E. Quellennec, Welcker (European members). Minority:—Messrs. Alfred Noble, Henry F. Abbott, Frederick P. Stearns, Joseph Ripley, Isham Randolph. (All Americans.)

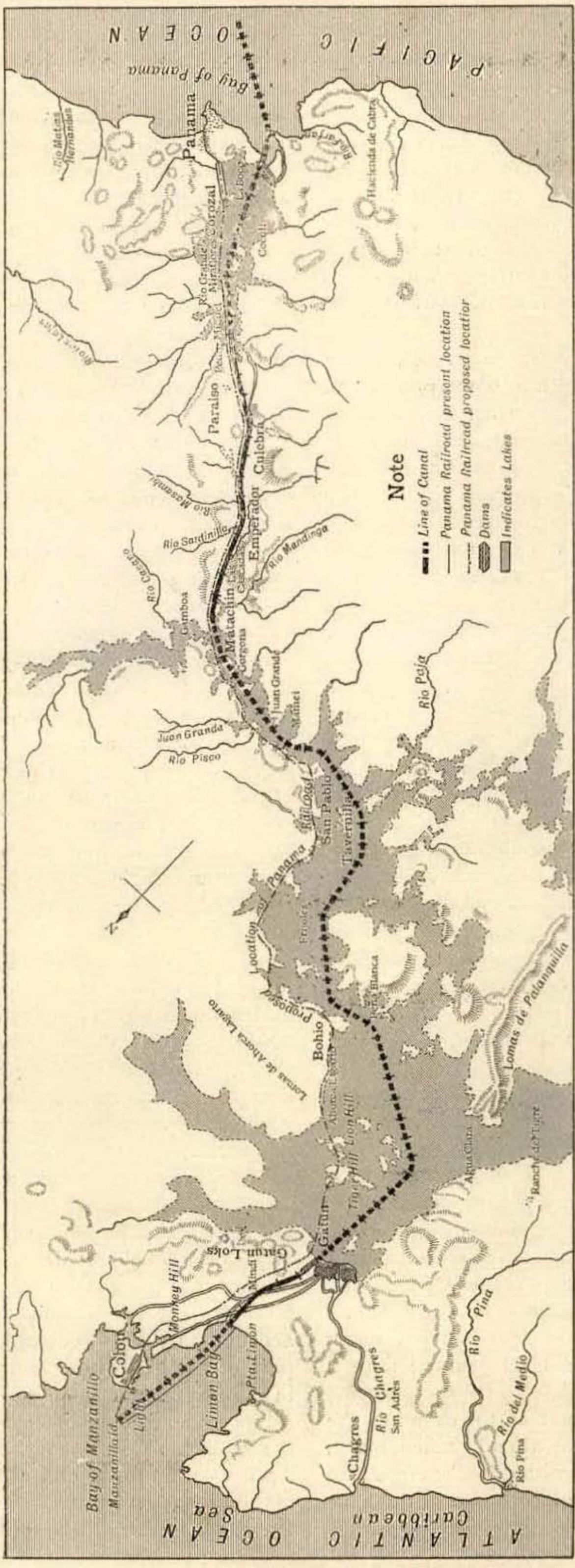


FIG. A.—PLAN OF THE PANAMA HIGH-LEVEL LOCK CANAL (summit elevation 85). (See Appendix, p. 270.)

danger of destruction in case of war or of seismic commotion; without counting the compulsory limitation to traffic owing to the limited quantity of water from the rivers that feed it (58,000,000 to 96,000,000 tons, according to the futute average size of the ships).

That project was defended with tenacity by the Government, and even represented as superior to the sea-level canal. Such a theory is as vain as that of the surgeon trying to demonstrate that a wooden leg is superior to a natural leg, and it did not convince the American Senate.

Then, in order to save the project, it was thought necessary to return to my proposition, and Senator Knox, in a speech that decided the battle, showed that the proposed lock canal would later on be transformed into a "true sea-level canal," a canal from 500 to 600 feet wide and 50 feet deep; that is the type of water-way I had proposed and called the "Straits of Panama." The project was adopted.

It seems at first glance indifferent whether the first form of the lock canal be realised with a summit level of 85 feet, or with a summit level of 130 feet above the ocean, if precautions are taken to ensure the ulterior transformation into veritable straits. Nevertheless, it is wholly different. The cut to be made in the dry is 53 million cubic yards for an 85 feet summit level, whereas it is only 20 milllons for the summit level of 130 feet. Besides, if this summit level is but a preliminary phase, an opening may be made with a narrower passage requiring only 12 million cubic yards. The widening would immediately follow the opening. Now, if 3 million cubic yards can be excavated annually, as it is proved, it will require 4 years for the passage at 130 feet, and 17½ years for the complete cut, made in the dry, and necessary for the passage at 85 feet.

This example shows the radical difference in opening the cut for a provisory summit level at 130, or for a definitive summit level at 85. Of course, great exertions may and will reduce the term of 17½ years, but these efforts are wasted in a struggle against nature to obtain finally an inferior solution, much more difficult to transform into a sea-level passage than a higher lock canal.

It is not without interest to examine the consequences that have already taken place, of the great error committed by the American Government in the final selection of the type of the canal.

Present Condition of the Work done by the American Government.—On March 3rd, 1881, the Universal Company of the Panama Canal was formed, and in November, 1883, the final plans were approved. We may take it for granted that one year and ten months were spent in studying, in boring, in clearing the virgin forest, in transporting the first plant, in building the houses and hospitals, and—in a word—in organising life and work in what had hitherto been wilderness. Three years after the beginning of actual works, by the 1st January, 1886, about 15,000,000 cubic metres (20,000,000 cubic yards) had been excavated. The totality of the constructions then covered a surface of 217,184 square metres (260,000 square yards), that is to say, a surface equal to that of a band extending along the canal from one ocean to the other, 3·2 metres or 10·5 feet in width. These constructions have since then been very much increased, and now cover a still larger area.

On January 31st, 1886, while I was chief engineer of the company, I had the honour of exceeding in the quantity of work executed, the total of 1,000,000 cubic metres per month (which for a long time had been aimed at), and of producing 1,067,823 cubic metres (1,397,000 cubic yards), during the month of January. The work was interrupted at the end of 1888; the total cubic volume executed by the Lesseps company amounted then to 72,000,000 cubic yards—the official figure furnished by the Isthmian Canal Commission in its reports of 1901 and 1906—which corresponds to an average cubic monthly output of 1,000,000 cubic yards during the six years of effective work. To this figure must be added about 8,000,000 cubic yards, executed by the new Panama Canal Company, between 1894 and 1904, the year when the American Government purchased the canal.

The value of this immense quantity of works, installations and plant, was estimated by the Isthmian Canal Commission, in round figures, at 33,000,000 dollars, that is £6,600,000 sterling, or 165,000,000 francs. It may be added, however, that the Commission only took into account 39,586,332 cubic yards as the sole part of the excavation that could be utilised in the execution of the plans it had adopted.

Since the recommencement of the work by the American Government, that is to say since April 1904, up to the end of 1906, the amount of the ground extracted for the excavation of the canal is about four million cubic yards.

In addition, dredgings have been executed at Panama and at Colon, but they have been done rather with the object of keeping in order the present installations. The total sum spent by the American Government in installations and work, up to the end of 1906, amounts to about 40,000,000 dollars (£8,000,000), that is to say to seven million dollars more than was paid to the French Company for their works, plant, and installations, according to the American estimates. The Isthmian Canal Commission certainly believed that it would produce a similar quantity of work, plant, and installations for an equal sum. We see now that with a much higher expenditure, four million cubic yards are excavated within about three years instead of 72,000,000 within six years. It would not be correct to suppose that the buildings, hospitals, and shops were no longer fit for use, and that new constructions had replaced them. The report of the Chief Engineer, Mr. Stevens, established on June 30th, 1906, the following statistics on the present distribution of the dwelling places :—

White married quarters—	
Built by the French	235
,, ,, Americans	73
Coloured married quarters—	
Built by the French	297
,, ,, Americans	20
White bachelor quarters—	
Built by the French	163
,, ,, Americans	12

It must be added that the work accomplished by the Americans in the sanitation is deserving of the highest praise. They have reproduced in Panama what they so perfectly did in Cuba five years ago. It is based on the application of the theory of Carlos Finlay, the Havana doctor, who discovered the origin of yellow fever a quarter of a century ago, and was not listened to until the admirable experiments of the American physicians demonstrated that it was true. But this work of prophylaxy consists especially in a rigorous sanitary police and does not require heavy sacrifices of money, nor the employment of a very great number of men. It has not interfered with the works of excavation proper. However, the success in stamping out yellow fever caused by the stygomia, a house mosquito, did not crown the efforts made against malaria, caused by the anopheles, a marsh mosquito.

During the first two years the small results of the works were explained by the need of a systematic organisation. "We have made 240,000 cubic yards in April," said Secretary Taft before a Committee of the House on May 24th, 1906, "but we have not begun yet, we are just ready to begin." In April Mr. Shonts in a report to the Secretary of War (Mr. Taft) wrote that a 1,000,000 cubic yards monthly excavation would be obtained from July on, but the maximum reached ever since was 325,000 cubic yards. Up to the present day the American Government has met only with bitter surprises.

PART IV.

CONCLUSION.

The general cause of the specified failure suffered by the Americans in the execution of the work and in the selection of the elevation of the first navigable summit level (not to speak of the unseemly error to dam the Chagres at Gatun), is due to their ignorance of the injurious influence of the rains on the excavation in the dry in the tropics. They have overlooked this essential element, which is the key to the whole situation, and they have refused to take into account the necessary system of excavation on water which appeared to me as the final teaching of the bitter experiences of the old Panama Company.

The Americans thought that by increasing the size of excavators, of cars, of locomotives, the cubature excavated would increase proportionally; but the contrary proved to be the case, as was to be expected.

A short extract from the message of President Roosevelt of December 17th, 1906, clearly brings out the fact :—

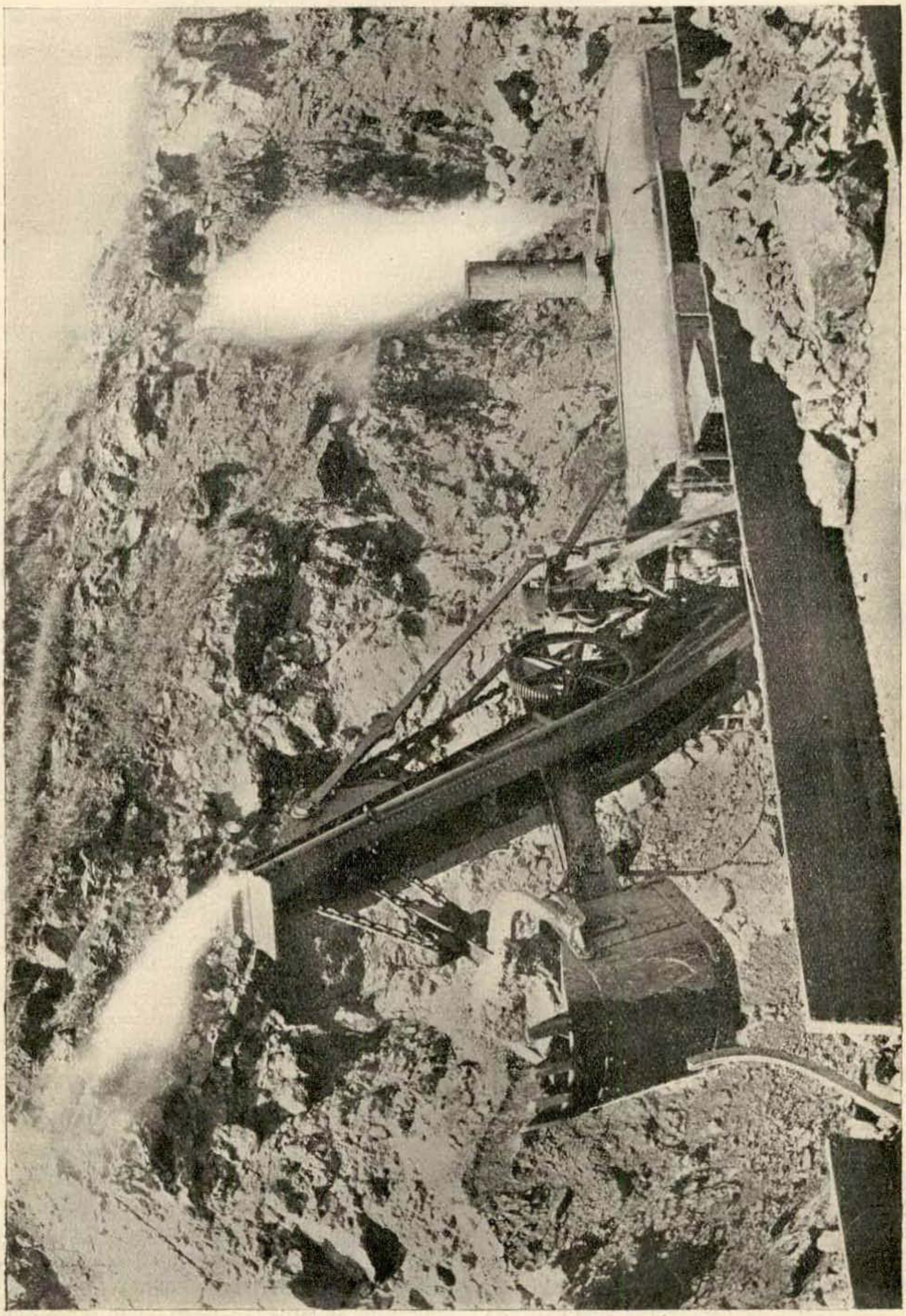
"The implements of French excavating machinery, though of excellent construction, look like the veriest toys when compared with these new steam shovels, just as the French dumping cars seem like toy cars when compared with the long train of huge cars dumped by steam ploughs which are now in use."

A little further on he says :—

"In the rainy season the steam shovels can do but little in dirt, but they work steadily in rock or in the harder ground."

President Roosevelt might say of the huge cars what he says of the steam shovels and add that, over the lines of the earth excavation works, these cars are permanently off the rails and not on them. (See Fig. G., p. 264 for the American plant, and Fig. K., p. 244 for the French plant.)

If the old Panama Company had committed the unpardonable mistake of measuring the weight of the locomotives and cars, according to the importance of the cut, and not according to the conditions resulting from the



G.—American Shovel at Work. (See Appendix, p. 272.)

ground and from the rain combined, if it had chosen the present American plant, it would have done absolutely nothing during nine months out of twelve. In fact, the President tells us that this plant accomplishes nothing in the soft ground during the rains, and almost the whole of the cuts, at the time of the French works, were in ordinary clay, not in rock or hard clay, as are the Americans now, thanks to the low level reached by the French excavations. Certainly the American engineers did not take these facts sufficiently into account, or they would have hesitated to compare to toys the plant which, 20 years ago, excavated, with fewer men than they themselves now employ, 1,400,000 cubic yards per month, in a much more difficult ground than they have now, while the so-called perfected machinery which they use, only yield them a record of 325,000 cubic yards per month (October, 1906). This is less than one-third of the volume officially announced last April by the President of the Isthmian Commission, as that which would characterise the monthly excavation for the second half of 1906 (1,000,000 cubic yards).

For the excavation of the high parts of the mountains, for the enormous and necessary work which they have accomplished, the French engineers have, therefore, acted wisely in choosing the locomotives of 30 tons and the cars carrying 10 tons of ground, which the Americans disdainfully call "toys." The enormous work accomplished by the French engineers under such difficult circumstances, the inability of their successors to attain—even approximately—the results which they achieved, largely compensate for the slight ridicule which is mingled with the accusation cast at them—that of having employed toys for this great battle with nature. The value of weapons—like that of tools—is not to be measured by their weight, but by their efficiency.

I have established that now, at this present stage of the work, dredges and barges should be substituted for the early plant which was necessary and well determined in the first period, and not heavier locomotives or steam-shovels.

It was at the commencement of this new phase that the Panama Canal came into the possession of America. The American engineers either did not know or would not understand, the marvellous facilities which this new period offered them if the proper method was used. Either they did not know or would not understand, the philosophy of this great problem, and how the way was opened up before them to realize in four years a lock canal communication between the oceans, and eleven years later the immortal and generous creation of the "Straits of Panama." Is it too late for a reaction? No, if the great question were examined in a purely scientific spirit. Yes, if national vanity steps in.

At one time it seemed as if President Roosevelt wished to exclude all narrow national tendencies from the scientific search for the best solution. This was when, in April, 1904, he decided to ask the English, French, German, and Dutch Governnments to appoint technical delegates to the Consulting Board, who had to decide on the best plan.

Unfortunately the question again entered into the sphere of petty national considerations, when several months later the President of the United States, on the 13th February, 1906, wrote in his message to Congress recommending the permanent lock canal:—"It will be noticed that the American engineers on the Consulting Board and on the Commission by a more than two to one majority favour the lock plan, whereas the foreign engineers are a unit against it."

Scientific truth is neither English, American, French, German, nor Dutch; it is the scientific truth, and belongs to the whole human race. No doubt each branch of the human race may pride itself on having helped in the establishment of such truth, but to be limited by the geographical boundaries of countries in the search after truth is to stray into voluntary error. This error was committed by President Roosevelt when he recommended the canal with permanent locks as being the American solution.

The monstrosity of placing permanently the future of the commerce of half a continent and the military security of the United States in a project which would be constantly menaced by accidents or earthquakes so impressed the Senate that the Senatorial Commission of the Isthmian Canal rejected the presidential recommendation. The Senate was about to act in a similar manner, when, at the last moment, Senator Knox, on June 19, 1906, saved the proposition, as we have seen already, by depriving it of its characteristic of perpetuity, and by accepting my formula, "the high-level canal first; the Straits of Panama afterwards."

He said: "Because the lock type of canal can, if necessity ever arises, be transformed

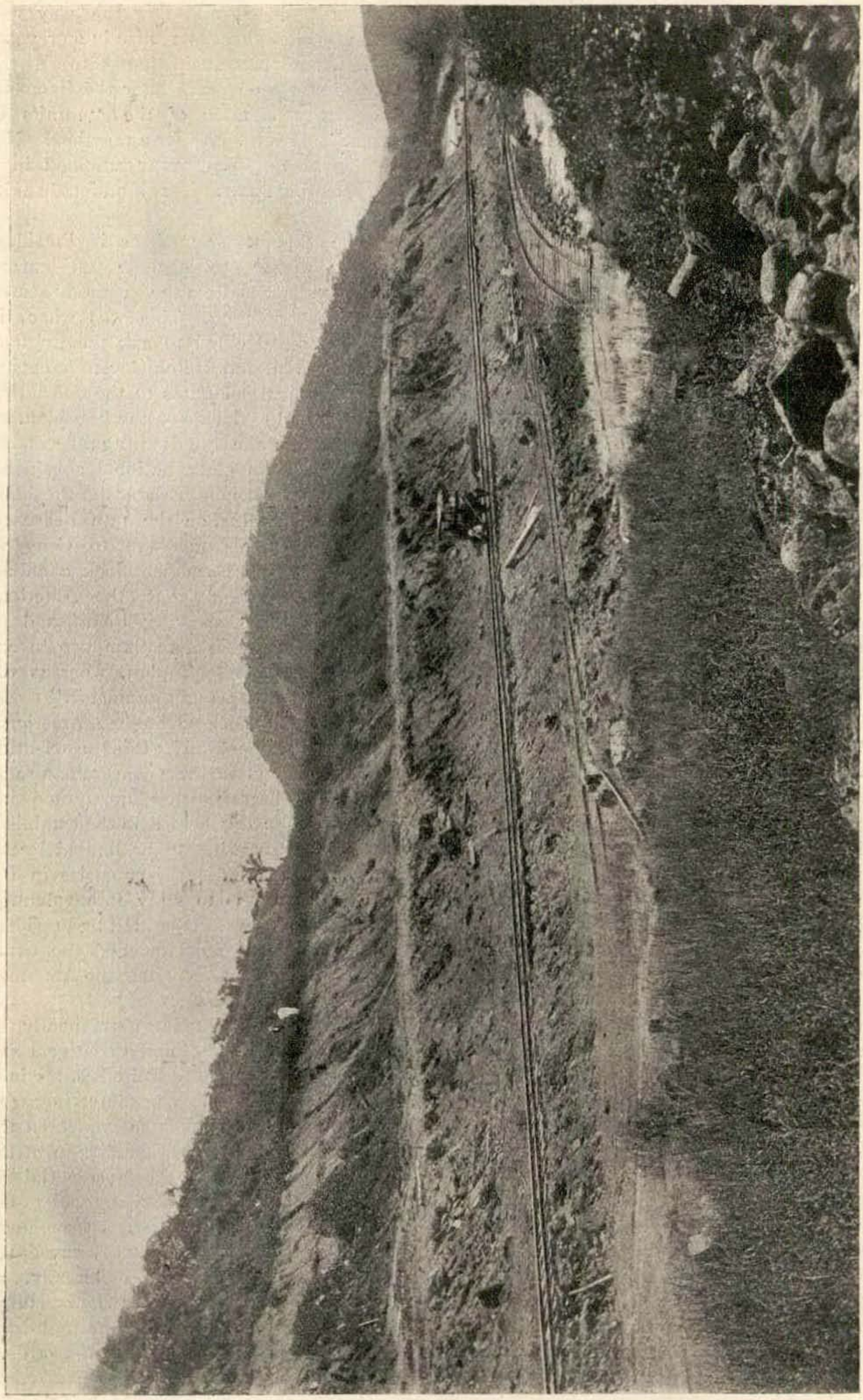


FIG. H.—VIEW OF AN EXCAVATION IN THE CULEBRA CUT (see Appendix, p. 273.)

into a true sea-level canal, one of five to six hundred feet in width, and fifty feet or more in depth of water." It was my proposition in its general terms; it caused the Senate to rally, and the canal with locks was accepted. But the form thus adopted for the first stage of the construction of the Straits of Panama, had to bear the consequences of the error which presided at its conception. It comprises an unnecessarily deep cut to be dug in the dry, and a needlessly wide and dangerous dam across the Chagres at Gatun.

President Roosevelt, notwithstanding the optimistic tone of his message of the 17th December last, owned that this dam, an earthwork with a length of 7,700 feet, and holding water at 108 feet above the bottom of the bed of the river, would entail "some little risk." This is a serious expression coming from the lips of the head of a country when speaking of the keystone of the vast enterprise to be undertaken. The successive consequences of the initial error committed in the conception of the project are manifest in the carrying out of the work. The President in his message speaks of the record breaking excavation of 325,000 cubic yards of October. He does not remark that it represents less than one-third of what his engineers expected to follow immediately the end of the period of organisation. The President is also bound to inform Congress that in April next the location of the locks will be finally settled. This is to admit that the locks are badly placed, that suitable sites are being still sought for and that, therefore, the final plan of the Government has not withstood the test of the first experimental works.

All these material facts and the enormous sums of money (£8,000,000 or 40,000,000 dols.) spent in two years and eight months without producing any serious results, should sound the alarm and show that the wrong track is being followed, and this mournful road leads to a dangerous and uncertain plan, which will, perhaps, replace the inauguration fêtes by a fearful cataclysm. Heroic courage is certainly needed in order to return to the truth, and if there be a man capable of showing this it is President Roosevelt. His latest message, however, does not seem to indicate that we may hope for it. Confidence obviously inspires the President in spite of these facts. That it is not well placed is sufficiently indicated by the photograph which we extract from his message with the inscription placed below. The President has obviously been deceived into believing that a new level 65 feet below the one created by the French had been dug through the entire Culébra cut seven miles long. The excavation referred to is simply the removal of an embankment 200 metres wide, 35 feet high, left across the cut opened by the French for the passage of trains. (See Fig. H., p. 266 and Explanatory note, p. 273.)

Except for this removal there has been no substantial change whatever in the general level created by the French. The amount of excavation done by the Americans is obviously too small to have permitted the creation of a new level 65 feet lower than the one existing when they took possession or even anything approaching it.

I am deeply distressed about this, for I had ardently desired that the work undertaken by the United States at Panama might add to their glory and not turn into a source of regrets and sorrows. I have done everything in my power to show the right path.

For years I have combatted in the United States the erroneous solution of the Nicaragua Canal, which, for half a century had been supported by the unanimous scientific and political votes of the Americans. I have triumphed over this legend, thanks to the constant help and to the boundless devotion of two great American citizens, Mr. John Bigelow and Senator Mark Hanna, who knew how to place national interest higher than national vanity, and to bow before scientific truth without regard to the nationality of those who struggled to attain it.

Later, when Colombia wanted to oppose the resurrection of the Panama undertaking, I co-operated in the work of the Isthmian secession, and as Minister Plenipotentiary of the new Republic, I signed, with the Secretary of State, Mr. Hay, the treaty between the two Republics by which the Panama Canal was born out of its own ashes.

I have again met in the person of Mr. John Hay, the noblest and purest-hearted of men; and the great Trans-Atlantic Republic, in losing Mark Hanna and John Hay, has also lost the sincere counsel of the noblest patriotism. They were no longer the councillors of the Government when I accomplished the third part of my task, when I brought forward the dearly-bought experience acquired by the old Panama Company. I showed how the work should be executed and what should be the object aimed at: the "Straits of Panama"—which might easily be completed in 15 years, after having opened a passage in four years or even less. I have spoken to the

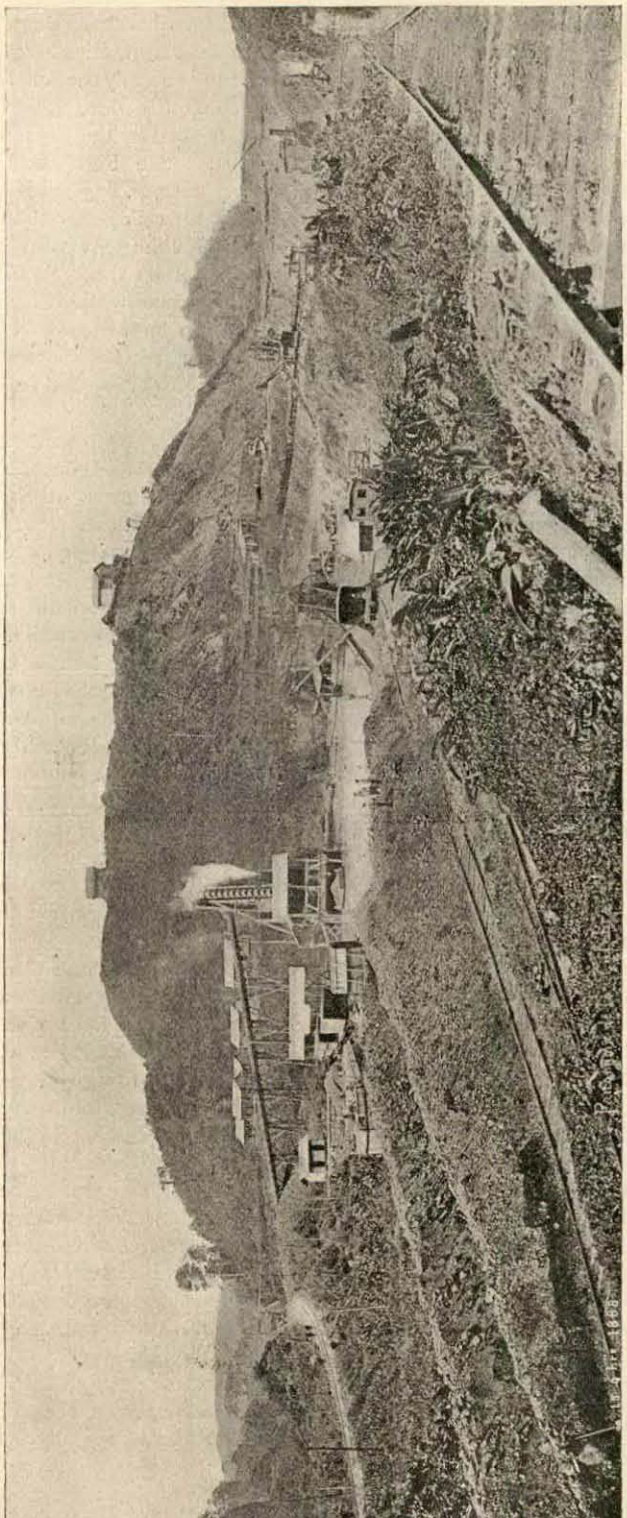


FIG. F.—INSTALLATION OF DREDGING WORKS MADE AT CULEBRA (1888). (See Appendix, p. 272.)

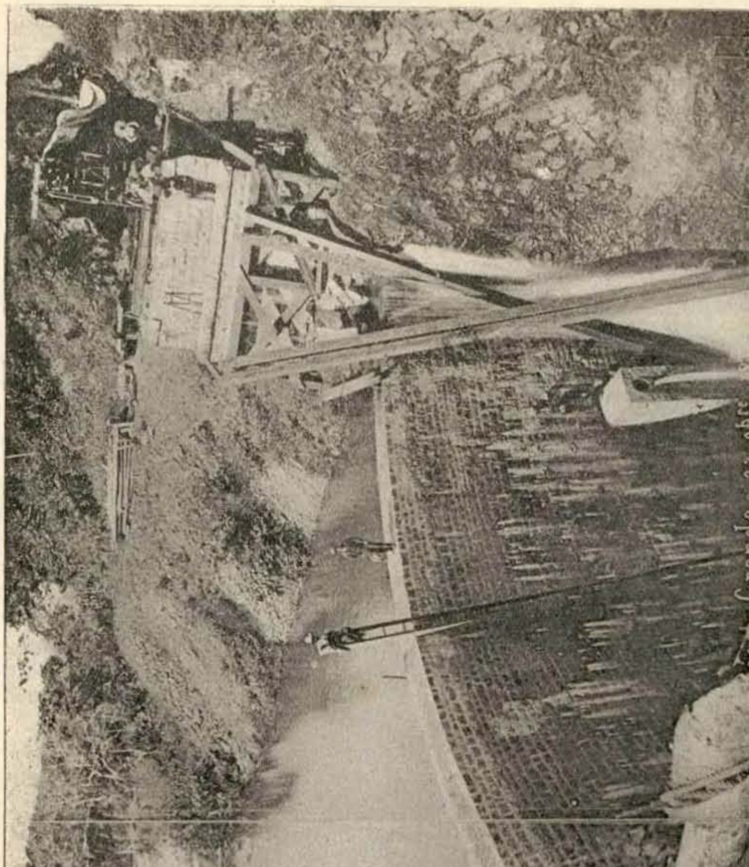


FIG. L.—RESERVOIR ON THE HIGH RIO GRANDE (1888), (see Appendix, p. 273.)

blind, who would not see; to the deaf who would not hear. Apparently what was wanted was something American, and what I brought forward was not American, though it was inspired by the American system of labour-saving appliances. The un-American system of labour-wasting appliances was considered for the first time as typical American.

Mr. Lindon Bates, a well-known American engineer, described this phase in a recent work ("The Crisis at Panama"):—

"When, three years ago, our Government took over the enterprise of the Panama Canal, it was with its proverbial enthusiasm. Our self-confidence was boundless. We would exhibit to the world how competent American business methods would put the water-way through. We had a subtle disdain for our predecessors—the impractical French. We tinctured in with pity: the visionaries. So we bought all their properties, channel right of way, railroad, charts, machines, scrap-heaps, and smiled, for we believed we had driven a Yankee bargain.

"One thing was overlooked, and the French, with idealistic generosity, threw it in. It had cost them six times what we were giving for their whole investment. Yet truly for us it was, of all, the most valuable asset —their experience. Had we bought it at a high price it might have been prized and have been let yield us precious saving service.

"But it too has been disdained, and in blind obliviousness, we head the old fateful way into the self-same pit.

"Labourers are wanted at Panama; the call has gone out from the Isthmus for fifty years.

"In the closing months of the French regime light dawned, and the word went forth—the minimum of men, the maximum of water-borne machines and land plant invincible to rain. This was the final dictum of a generation's experimenting." See Fig. F., p. 268, and Fig. L., p. 269.)

However this may be, I have done my duty as a sincere friend of the United States, and have endeavoured to point out to their engineers the road to be followed. At the same time—and this was my principal object—I have done my duty to my own country in showing that its engineers from the very beginning were equal to the great task which they had undertaken; in showing that our intellectual patrimony may claim the honour of having found the solution of the problem set by Charles the Fifth in 1523 to Cortes: Discover the Secret of the Straits (*el Secreto del Estrecho*).

This secret, as I have shown, is henceforth brought to light. It does not lie, as Cortes and his successors imagined, in the geography of the Isthmus, but in its topography and in its hydraulics. Everything has been prepared by nature for hydraulic power to lift, in the high valley of the Chagres, the earth and the rocks which obstruct the site of the Straits. Harness this power, and the Straits will be made by its spontaneous action. This is the "Secret of the Straits."

APPENDIX.

EXPLANATORY NOTES, FIGURES A. TO M.

A.—*Plan of the Panama High-level Lock Canal (summit elevation, 85') adopted by the American Government.* (Original project of Godin de Lépinay, 1879). (See p. 261.)

NOTE.—Godin de Lépinay had indicated the Gatun location for the dam in his plan, under the reserve that it would be recognised a possibility there; he said that in the contrary case the location ought to be Bohio, 9 miles up the river (14 kilometres).

The only reason which actuated the American minority of the Consulting Board in choosing Gatun, which always had been condemned ever since Lépinay mentioned it as a location for a dam, must be attributed to their great desire to prolong as much as possible the limit of exploitability of a lock canal. This limit is fixed by the minimum average yearly output of the rivers feeding the summit. This limit corresponds at Bohio to a transit of 40 to 60 million tons. As the Sault Sainte Marie Canal has already reached 44,000,000 tons traffic, a lock canal at Panama with the limit corresponding to the Bohio dam, could not be called but a temporary solution in America. With a dam at Gatun the water output is half greater than at Bohio, and the limit of exploitability is from 60 to 100 million tons. This enabled the minority to dispose of the objection which any lock canal at Panama finds, its narrow future. They even tried to go further and said the limit could be extended with more dams—this is erroneous, more dams do not give more rain.

B.—*Longitudinal Section of the Panama High-Level Lock Canal (summit elevation, 85') adopted by the American Government in* 1906. (Original project of Godin de Lépinay, 1879). (See Supplement.)

NOTE.—This project, recommended by the minority of the Consulting Board as the perpetual solution of the Panama problem, was endorsed by the American Government and proposed to the Congress of the United States (February 19, 1906). It was voted down by the majority of the Senatorial Isthmian Canal Committee, but was finally adopted by the Senate (June 21, 1906) on the strength of Senator Knox's declaration that it could be transformed "into a true sea-level canal, one of 500 to 600 feet in width, and of 50 feet or more depth of water," that is to say, into the "Straits of Panama" (Bunau-Varilla project, 1905).

The vital objections to this very bad solution is (1) The magnitude of the summit level cut to be excavated in the dry (53,000,000 cubic yards); (2) The erection at Gatun of a huge, dangerous, and badly-located earth dam, 7,700 feet long, of 21,000,000 cubic yards volume, holding the water 85 feet above sea-level, across a river, the bed of which is 22 feet below sea-level. The method of construction is the one proposed by Mr. Bunau-Varilla for the small and low dam at Bohio and consists in depositing dredged soil by means of centrifugal pumps. The ground, excellent at Bohio, is unfit between Gatun and the sea, being largely marshy silt incapable of settling; (3) The advantages offered by dredging in the transformations of a high-level canal diminish when the snmmit is lower, and more ground must be excavated in the dry above the level of work of the dredges; (4) The location of the locks in this plan are in a bad ground, and the site chosen has proved inadequate.

The longitudinal profile of the Panama Route shows:—

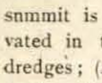
1st. The original natural ground along the axis of the canal.

2nd. The lowest point reached by the excavation in every cross-section. (Between this lowest point and the original natural ground the cut is entirely open, but necessitates in most places widening.)

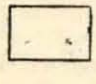
3rd. The water-level and bottom line of the High-level Lock Canal (85′), the location of locks and dams.

4th. The mean water-lever and the bottom line of the Straits of Panama.

Excavation actually made by the French companies —60,000,000 cubic metres or 80,000,000 cubic yards,

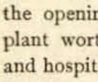


approximately (including deviations), (of which about 9-10ths resulted from the works of the old Panama Company, and 1-10th from those of the new Panama Company), the works of the old company having been accomplished within eight years, including more than two years for the first surveys, the opening of the country, the transportation of a plant worth 30,000,000 dol., the erection of houses and hospitals, &c., leaving between five and six years for the works proper, now represented by an excavation of 55,000,000 cubic metres, or 72,000,000 cubic yards.



Excavation to be made to open the High-level (85′) Lock Canal (bottom width 200′, water depth 42′) — total excavation through the central mass, 53,800,000 cubic yards.

Excavation to be made for the transformation, without any interruption of transit, by floating



dredges of the High-level Lock Canal (85′) into the Straits of Panama. Bottom width 500′, water depth 45′ at the lowest tides)—457,00,0000 cubic metres, or 600,000,000 cubic yards (including the volume of excavation of the High-level Lock Canal).

Such excavation would be reduced to 156,000,000 cubic metres, or 205,000,000 cubic yards, if the transformation would simply aim at the creation of the narrow, shallow, Tide Locked Sea-level Canal, usually termed the Sea-Level Canal, which, if constructed immediately by the usual methods of excavation, steam shovels on rail, and railroad transportation of the spoils to the dumps, would require for the opening of transit a period of time about equal to the sum of the two periods necessary first for building the High-level Lock Canal, and second, for transforming it into the Straits of Panama.

C.—*Plan of the Panama High-level Lock Canal (summit elevation 130′). Constructible in four years (first phase) in order to be later transformed into the "Straits of Panama" (second phase) without interfering with navigation.* (Bunau-Varilla project of 1905). (See p. 252.)

Note.—This plan is the same as for the lock canal at elevation 170′, only two more locks have to be added. It has appeared unnecessary to make a special plan for the particular project, the location of the locks being shown in the longitudinal sections.

D.—*Longitudinal Section of the Panama High-level Lock Canal (summit elevation 130′). Constructible in four years (first phase) in order to be later transformed into the "Straits of Panama" (second phase) without interfering with navigation.* (Bunau-Varilla project of 1905). (See Supplement.)

Note.—The governing ideas of the conception of the high-level lock canal at elevation 130′ is 1st, to reduce to the minimum the amount of excavation of the central cut so as to be sure to dispose of it in 4 years, without too much elevating however the summit. 2nd, to reduce as much as possible the height of the dam at Bohio. In this plan the head of water is reduced to a maximum of 60′ above the sea, the level of the ground of the valley being 30′ above the sea, and the bed of the river being at sea-level.

The method proposed by M. Bunau-Varilla for erecting this easy dam and which was so unhappily applicated by the minority of the Consulting Board for the Gatun dam, consists in bringing, in scows, dredged material from the neighbourhood to the site of the dam and to pump it on the dam location. The ground is excellent at Bohio, very bad at Gatun. The length of the dam at Bohio (1285′ at the crest) is about six times smaller than at Gatun, and its height above the bed about half the height of the Gatun dam. 3rd, the lock canal being temporary the locks can be smaller than in a perpetual lock canal.

The longitudinal profile of the Panama route shows:—

1st. The original natural ground along the axis of the canal.

2nd. The lowest point reached by the excavation in every cross-section. (Between this lowest point and the original natural ground the cut is entirely open, but necessitates in most places widening.)

3rd. The water level and bottom line of the High-level Lock Canal (130'), the location of locks and dams.

4th. The mean water-level and the bottom line of the Straits of Panama.

Excavation actually made by the French Companies.

(See note to Diagram B.)

Excavation to be made in four years to open the High-level (130') Lock Canal (bottom width 150'—water depth 35')—total 45,000,000 cubic metres or 60,000,000 cubic yards approximately, of which 20,000,000 cubic yards only are to be excavated in the central cut, making necessary a total yearly output (15,000,000 cubic yards), inferior to that reached by the old company (16,000,000 cubic yards).

Excavation to be made for the transformation, [wit]hout any interruption of transit, by floating dredges of the High-level Lock Canal (130') into the Straits of Panama, (Bottom width 500', water depth (45' at the lowest tides)—457,000 cubic meter. or 600,000,000 cubic yards (including the volume of excavation of the High-level Lock Canal).

E.—*Longitudinal Section of the Panama High-Level Lock Canal (summit elevation,* 170'), *constructible in three years for a limited traffic such as that of military navigation, in order to be later transformed into the "Straits of Panama," without interfering with navigation.* (See Supplement.)

NOTE.—It is the Bunau-Varilla project of 1905 modified in view of reducing to the lowest limit the works necessary to the opening of interoceanic communication, and therefore the time necessary.

The governing ideas of this project are the following:—1st. In order to eliminate the time necessary to open a cut through the summit, the water is raised high enough to form a continuous level which dredges will widen and deepen, or to reduce the work in the dry to an insignificant amount if it is thought preferable to dig during the erection of the locks. 2nd. In order to eliminate the major part of the time necessary for the masonry of the locks, it will be limited to the heads of these works, the slopes of the cuts will limit laterally the body of the locks. 3rd. The outlet of Lake Bohio will be opened through the canal cut laterally to the locks. 4th. The locks will be single and sufficient for the largest men-of-war. 5th. In order not to wait until the dam at Gamboa is erected, a steam pumping-station will be established near Gamboa to feed the summit level for the limited traffic referred to during the dry season, and help the Obispo River during the wet one.

This conception would correspond to the opening of navigation for military purposes during the executions of the Straits of Panama by dredging, and would greatly facilitate the works by giving free access to the plant from the sea to the summit level.

The longitudinal profile of the Panama route shows:—

1st. The original natural ground along the axis of the canal.

2nd. The lowest point reached by the excavation in every cross-section. (Between this lowest point and the original natural ground the cut is entirely open, but necessitates in most places widening.)

3rd. The water-level and bottom line of the High-level Lock Canal (170'), the location of locks and dams.

4th. The mean water-level and the bottom line of the Straits of Panama.

Excavation actually made by the French companies.

(See note to Diagram B.)

Excavation to be made in three years to open the High-level (170') Lock Canal (bottom width 150', water depth 35').

Excavation to be made in 10½ years for the transformation, without any interruption of transit, by floating dredges of the High-level Lock Canal (170') into the Straits of Panama. (Bottom width 500,' water depth 45' at the lowest tides)—450,000,000 cubic metres or 600,000,000 cubic yards (including the volume of excavation of the High-level Lock Canal.)

F. — *Installation of Dredging Works made at Culebra (Pacific slope) in* 1888 *by M. Bunau-Varilla, about* 18 *metres,* 60 *feet above the Rio Grande river.* (See p. 268.)

NOTE.—Owing to the lack of water communications, which then were not easy to establish with the projected Lake of Gamboa, the spoils were then dredged again and sluiced into the Rio Grande valley. This was temporary. It was intended to remove by railroad transportation the redredged material until the water communication could be established with the Gamboa Lake. This precious installation was blindly abandoned by the new Panama Company and the floating plant put aside. It astonished very much the American engineers to find naval plant on the top of the Culebra cut. "What man does not understand," said Goethe, "he makes fun of." The Secretary of War, Taft, materialized this thought of Goethe when he said to a Committee of the House: "Mr. Stevens, the Chief Engineer, has got a launch which was found on the top of the Culebra cut, that he took down from there, and had repaired, and is now using at La Boca. They (meaning the French) apparently thought the water was coming up the top of the cut and they would get the launch there in time."

G.—*American Steam Shovel At Work.*

It is to this type of steam shovels that the American opinions attributed erroneously the future solution of all excavation problems. (See p. 264.)

The American engineers have been led to recognise that the difficulties of the Isthmus are entirely in the transportation, and not in the loading of the material. (This photograph is extracted from the message of the President of the United States, December 17th, 1906).

H.—*View of an Excavation in the Culebra Cut.* (See p. 266.)

NOTE.—This picture is extracted from the Panama message sent to Congress on the 17th of December, 1906, by President Roosevelt, on his return from the Isthmus.

This picture appears in the message with this line below: "View in Culebra Cut. The level at which the two men are standing is that reached by the French; the level at which the motor-car stands is the present American level—65 feet below."

Everybody reading the message cannot help believing that a new level 65 feet below the lowest, left by the French across the Culebra Cut (seven miles long) has been excavated by the Americans.

There is, unfortunately, not the shadow of a reality in such a belief which the line below the picture above necessarily creates. President Roosevelt must have been deceived by some false explanation, otherwise he would not have inserted such a statement in a public document bearing his respected name.

For the necessities of railway communications, the Panama Company had left a short mass of ground (200 to 300 yards long) 33 feet above the general level they created at 157 feet (48 metres) through the Culebra Mass, originally 333 feet high above the seaon the axis, and 300 at the lowest point of the saddle. This small mass of ground has been removed by the Americans. It has the importance of the removal of a railway embankment. It is not the creation of a new level. Nothing else can give the colour of reality to the phrase reproduced above. The report of the Isthmian Canal Commission for the year ending December 1st, 1906, says:—"The engineering work of the year has been almost entirely preparatory. . . . . . The general plan of the work which has been done in the Culebra Cut has been in putting the various levels in proper conditions for the maximum number of steam shovels." Such capital work, then, as the creation of a new level 65 feet below the level reached by the French, has never been made.

I.—*Twelve-ton Lobnitz Rock Cutter working in the Manchester Ship Canal*, (from *Engineering*, August 17th, 1906, kindly lent by the editor of *Engineering*). (See p. 248).

NOTE.—The average cost in ten months, of operating this machine for loosening the rock and transforming it into a material as easily dredgable as sand was 8·94 pence per cubic yard in spite of the interruptions of the works by the ships. (Figures given by Mr. Hunter, chief engineer of the Manchester Ship Canal.)

J.—*Comparative Cross Sections.* (See p. 240.)

The hulls represented in the drawings above are those of the new Cunarders, *Mauritania* and *Lusitania*. Their beam is 88 feet, their draught of water 36 feet. They would pass the "Straits of Panama" with 9 feet below the keel at the lowest stages of the tide, and with ample room to cross each other. They could not pass the Panama sea-level canal for want of depth, and they could not cross each other if they had the necessary depth. This was partly remedied by the Consulting Board. The majority gave 40 feet depth, and the minority 42 to 45 feet depth to the canal. In both cases the cut at Culebra, 200 feet wide, does not allow the crossing of such ships.

NOTE.—The two cross sections correspond to the average altitude of the ground on the axis in the Culebra cut, 181′ $\frac{7}{10}$ (55 m. 43.). The depth of water in the "Straits of Panama" is the average depth at mean tide in the Culebra cut.

The time of construction by wet process of the "Straits of Panama" is estimated at 15 years, the expenditure is estimated at £30,000,000. The excavation is estimated at 600,000,000 cubic yards.

The time of construction by dry process of the "sea-level canal" is estimated at 22 years, the expenditure is estimated at £60,000,000 by the Isthmian Canal Commission, the excavation is estimated at 205,000,000 cubic yards.

K.—*Works in the dry (Culebra) as they were installed in* 1888 *(looking towards Panama) by the old Panama Company (de Lesseps Company).* (See p. 244.)

L.—*Reservoir on the high Rio Grande, created in* 1888 *by M. Bunau-Varilla for feeding the dredging pond he installed on the slope (Pacific side) of the Culebra Saddle, and which is represented in drawing F.* (See p. 269.)

This reservoir has been used by the Americans 16 years later to feed the town of Panama with drinkable water.

M.—*Works in the wet. Dredge working in Blasted Rock*, 1888. (See p. 245.)

NOTE.—After M. Bunau-Varilla removed in 1885 rock under water at a moderate price (8 francs a.c.m.), the contractor in charge of the Mindi Hills preferred drowning the open-air excavation in the rock and attack it by dredge, after mining and blasting it either above or below water. This shows that already in 1887 it was deemed more economical to mine under water the rock and to dredge it, than to excavate and to transport it in the dry. Now, with the electric and large dredges with the Lobnitz cutters, this is ten times more true.

DISCUSSION.

The CHAIRMAN, in opening the discussion, referred to the fact that the author had been connected with the Panama Canal since 1884, at which time he was in co-operation with M. de Lesseps, who was the prime mover in the starting of the great scheme. The audience therefore had had the pleasure of listening to a gentleman who had had more than usual opportunities of making himself acquainted with the project in general and with the special difficulties which had to be surmounted. All had listened to the author's description of the Panama Canal and the problem which had to be solved with very great interest, and felt that he had given his whole heart to the solution of the problem of the secret of the Straits. The author was an entirely independent gentleman so far as the present undertaking was concerned, and he had come that evening to give to the Society, and through the Society to the world, his well-considered views as to the proper mode, and, in his opinion, the only mode, of bringing the work to a successful issue. He (the Chairman) was afraid that, without more study than one could give to a subject which was abstruse, it was very difficult to express any opinion on the author's views, but in principle one could not help being captivated with the idea that the work could be constructed and brought to a proper issue by the use of water as the carrying power for the machinery to do the excavation, and as the carrying power for the transport of the dredged material to its destination. One could not help being struck also with the great ingenuity by which a large receptive place could be made where the dredged material might be deposited, at a level which was sufficiently convenient for the barges to reach. The mode of carrying out the work as described by the author, the number of barges which would have to be employed, the number and the size of locks which would be necessary in order to perform the work in any given time, and the quantity of material which would have to be transported were matters of careful calculation for the engineers, with which the present meeting had nothing to do. The broad principle commended itself to an engineer at once, that if it was possible to use the flotation power of water to bring the excavators to the place where the excavation had to be made, and if it was also possible to take the barges from the dredger to the place for which they were destined, it would solve some of the greatest difficulties of dealing with such a work in such a country. As the author said, instead of treating the great rainfall as an enemy, he converted it into a friend and an ally; and if that plan could be carried out, it seemed to him a most valuable suggestion. His own experience went to corroborate these views entirely, because he very well knew the cost of excavating in waterlogged strata when the excavation was made in the dry, where the rain caused innumerable slips of earthwork and occasioned the greatest difficulty in maintaining the roads. If these difficulties could be avoided, an enormous amount of trouble was done away with, and a price was reached which was far and away less than anything which could be contemplated for excavation in the dry. He supposed one might almost say that the Suez Canal would have been impossible of construction if it had not been for the great improvement in dredging plant which took place about the time that the problem had to be undertaken, although in that instance the distances to which the earth had to be transported were comparatively short. Since that time the development of dredging plant had gone on by leaps and bounds, and engineers were now able to use dredgers supported by water at the spot where the work had to be done of a power and celerity of excavation which were never dreamed of in former years. All those developments had taken place within the memory of those present, and they were not yet at an end. The only point which struck him adversely in the paper was where the author talked of excavating with dredgers which were 16 years old. He thought the author in that instance could only have been referring to an experimental excavation because personally he should be very sorry to undertake to go on with the Panama Canal with dredgers built 16 years ago when he could now obtain dredgers of a very superior character and of much greater power. He had had something to do with the Suez Canal, and could speak from experience with regard to the question of the excavation of rock under water. Mr. Quellennec the consulting engineer of the canal, knew the price of the work much better than he did, but the matter was brought before him while he was a member of the International Consultation Commission on the Suez Canal. It was at one time considered that the excavation of the rock between the Bitter Lakes and Suez for the purpose of deepening the canal to suit the modern requirements of ships presented such a serious obstacle that the work was suspended for many years, although everybody knew it would have to be done. But that difficulty disappeared. The work was done without explosives, the traffic of the canal was not interrupted, and the price at which the excavation of the rock under water was done was given by Mr. Quellennec at 1s. a yard. Mr. Hunter had also stated that he excavated the rock in the Manchester Canal under water by the same Lobnitz process at 9d. per cubic yard; and those prices engineers must take as facts. Taking those prices as true (and they must be so considered on the evidence of such eminent engineers) it did seem a very startling proposition that engineers should be contemplating at the present time such a very large price for the Panama Canal as 10s. a cubic yard for rock excavation. He also desired to say that he could, more or less, corroborate from his own knowledge the prices the author had quoted for the dredging of soft material. He had excavated and removed to a distance many millions of yards of such material; and in addition to that engineers were now, under more modern principles, excavating material and pumping it for half a mile or 1½ miles through large pipes without the least difficulty and at a very moderate price. That again showed how very much could be learned when one had to deal with a dredging system compared with an excavation system. The grandeur of the author's conception struck him at once as one which all would like to see completely considered. Although the cross section of Panama Canal, as proposed by the Commision, was much larger than the Suez Canal, it was comparatively small in view of the constant augmentation of the size of ships, and he thought it would be found that the Isthmian Canal was already doomed as too small for the requirements of the future. He, therefore, thought everyone would welcome the idea which the author had enunciated, that they need not be content with what one might call a canal but look forward to what had been better described as the Straits of Panama. Another thing which struck him was that the recent sad experiences which had taken place at Jamaica, Valparaiso, and California seemed to indicate that a great work of international importance in such a locality as Central America and the Isthmus of Panama ought, if possible, to be so designed that what were called works of art should be altogether avoided. A system of a lock canal in a volcanic neighbourhood subject to earthquakes could not be looked forward to with complacency; and when the enormous amount of money which was to be spent on the work was taken into consideration, it seemed to him as an outsider—because he was only an outsider in this particular matter—that anything in the nature of large masonry dams and locks closed with gates, which would be absolutely wrecked by comparatively small shocks of earthquake, should be avoided in such a magnificent undertaking.

Mr. E. W. MOIR said he did not know much about the Panama Canal, but he could fully endorse the author's statements with regard to the advantages of dredging as against excavation in the open, and also the increased power of modern dredging plants compared with what was possible within comparatively recent times. His own firm of S. Pearson and Son had extensive dealings in dredging plant, and only in the previous week placed with Messrs. Lobnitz an order for a dredger which was guaranteed to put out over a thousand yards an hour from a depth of 45 feet in soft ground. The buckets were of a cube capacity of one metre, and guaranteed to travel at the rate of 18 buckets per minute. He had often had conversations with Mr. Lobnitz about his rock-breaker. Mr. Lobnitz's father began the work of building dredging plants on the Clyde, and the son was ably carrying on the work in his father's footsteps, and told him that quite recently he had seen figures of the Manchester Ship Canal costs which indicated that sub-aqueous rock dredging was being carried out at a smaller figure than it was possible to take out the same rock with ordinary boring and explosives on the surface. That evidence, therefore, conclusively confirmed what the author had said. He thought the reason the Americans had decided on the lock canal system was largely due to their desire to have the canal pushed through within the memory of the present generation. While the International Commission exclusively reported in favour of the sea-level canal, although of course on a much smaller section than that suggested by the author, they felt that it would take too great number of years to make. His firm was very interested in the Isthmus of Panama, and Sir Weetman Pearson was only on that very day opening the Tehuantepec Railway, and the connecting harbours. For the last eight years, Sir Weetman had been erecting a railway across the Isthmus of Tehuantepec, and building two ports, one at Coatzacoalcos, on the Gulf of Mexico, and the other at Salina Cruz on the Pacific, which would give from the present day a communication of much less distance than anything now existing, or that would exist even after the Panama Canal was completed. The distance between New York and San Francisco was 1,000 miles less than it would be between the same places by the Panama Canal when completed, although the railway was only 192 miles long. His firm were in partnership with the Mexican Government in the control and working of the railway, and they expected great things for international trade. One line of steamships, instead of going round the many thousands of miles *viâ* Cape Horn, had arranged for its freight to pass over the Isthmus; and, due to the fact that Americans were wise enough to insist that all coast trade should be carried in American bottoms by American seamen, a very large sum of money had been invested in ships under the American flag to carry the freight from New York to San Francisco.

On the motion of the CHAIRMAN, a hearty vote of thanks was accorded to Mr. Bunau-Varilla for his interesting and instructive paper.

Mr. BUNAU-VARILLA, in reply, remarked that reference had been made to the enormous strides which had taken place in water-borne excavation compared to earth-borne excavation. Outside of those due to the enormous increase in the size and power of the dredges, there is another which will play an important part in Panama—the use of electricity. On board a dredge, the actual cost of the dredging lay not so much in the work done as in the time lost and the occurrence of accidents. As dredges are excavating material they cannot see, they are exposed to hidden obstacles, and abnormal resistance is from time to time imposed upon the machinery. But when the motive power is electric, as soon as the resistance comes to a fixed limit the current stopped and the accident avoided. That is a very important factor in the cost of the work. In 1895, while he was constructing a railway in the west of Spain, he took advantage of having to remove a large quantity of ballast from the river Esla to make experiments with regard to the adaptation of electricity to dredging, and they entirely fulfilled his expectations. The employment of electricity on board a dredge led to a considerable economy in time by the prevention of small accidents. He could not conclude without expressing his deep gratitude for the hospitality which had been shown him by the Society of Arts. The hall of the Society was a most suitable place in which to state his opinions, because it was neutral and friendly, and situated in a country which was closely linked with his own by ties of the deepest friendship.

THE RAILWAY AND TRAMWAY SYSTEMS OF JAPAN.

The first Government railway built in Japan was that between Tokyo and Yokohama—eighteen miles—which was opened in 1872. From that time the Government made every effort to construct more lines, until by the financial year 1882–3, 150 miles had been completed. The railway was at the time generally looked upon as a Government undertaking, and no attempt was made among the general public to engage in railway enterprise. In 1883, however, a private company was for the first time formed for the construction of railways, and thereafter railway enterprise made gradual progress among the people. In 1887 the Private Railways Regulations were issued, and both Government and private railways increased and grew rapidly in prosperity. At the present time private lines have, in mileage, left the Government lines far behind. In March, 1900, the Private Railways Law and the Railway Traffic Law were promulgated, thereby completing the legislation, private and public, in respect of railways. In March, 1905, the Railway Mortgage Law was issued with the approval of the Imperial Diet, and opened the way for the circulation of capital, for this law enables a private railway company to form a railway foundation with the whole or part of its railway lines, land for railway use, buildings, machinery and appliances for railway use or appertaining to the railway, and rolling-stock and appliances appertaining thereto, and make such foundation the object of a mortgage right. The principle of railway nationalisation first took effect in Japan when railways were projected between Shimbashi and Yokohama, and Kyoto and Kobe, and in 1892 was established the Railway Construction Law, which mapped out the important lines throughout the country, and indicated the general plan of working such lines by means of railway loans. Before, however, this law was passed, it had been decided that it would, for the purpose of effecting a speedy construction of railways, be best to leave such construction to private enterprise, and in 1887 the Private Railways Regulations were issued. Since then Government and private lines have extended side by side. At the present time, in view of the necessity for a definite post-bellum programme and for the increase of national wealth and development of national resources, it has, according to a recent report of the Japanese Ministry of Finance, become of the utmost importance to introduce effective means of internal transportation and communication. In addition to the Government lines, there are more than thirty private railways, and even the principal trunk lines running from Hokkaido to Kyushu are under the control some of the Government and others of various private companies, so that the traffic on them lacks order and uniformity. For these reasons the Japanese Government decided upon the State ownership of all railways that are used for general traffic, leaving out those of merely local importance, and proposed to purchase the lines belonging to thirty-two private companies within a period extending from 1906 to 1911, and the Seoul-Fusan Railway in 1906. Accordingly the Railway Nationalisation Bill and the Seoul-Fusan Railway Purchase Bill which embodied these plans, were presented to the Imperial Diet, and were duly passed, with an amendment made in the House of Peers, by which the number of companies to be bought out was reduced to seventeen, and the period of purchase extended. The lines to be purchased under the Railway Nationalisation Law are those belonging to seventeen companies, namely, the Nippon, Sanyo, Kobu, Kwansai, Kyoto, Hankaku, Hokuyetsu, Nishinari, Nanao, Ganyetsu, Kyushu, Hokkaido-Tanko, Hokkaido, Sangu, Sobu, Boso, and Tokushima, all of which are main trunk lines used for general traffic. Their aggregate length is 2,812 miles, and cost of construction about £23,463,000. The Government is to purchase the above-mentioned railways within a period of ten years from 1906 to 1915. The purchase price is to be calculated in the following manner:—(*a*) An amount equal to twenty times the sum obtained by multiplying the cost of construction at the date of purchase by the average ratio of the profit to the cost of construction during the six business terms of the company from the second half year of 1902 to the first half year of 1905; (*b*) the amount of the actual cost of stored articles converted according to current prices thereof into public loan bonds at face value, except in the case of articles which have been purchased with borrowed money. The first electric tramway built in Japan was a line eight miles in length opened in Kyoto in 1895, when a national industrial exhibition was held in that city. Since then, other cities of importance have in succession constructed electric tramways as convenient means of communication for short distances, so that there are now eighteen electric tramway companies, with an aggregate capital of £3,891,000, whose lines already opened total 130 miles, with 82 miles in addition under construction. Most of the companies, however, are still in the initiatory stage and do not yet make a very profitable business of the undertaking. That the profits will be large, however, is clearly shown by the fact that the electric tramways of Tokyo already pay annual dividends of not less than 10 per cent.